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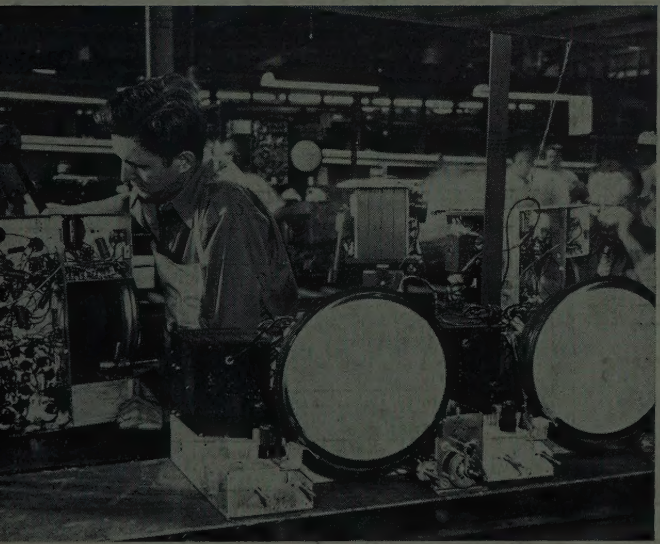

RCA Victor Division

VIGOROUS TESTING

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PROCEEDINGS OF THE I.R.E.

Table of Contents, Indicated by Black-and-White Margin, Follows Page 32A

The Institute of Radio Engineers

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PROCEEDINGS OF THE I.R.E.

INSTITUTE NEWS AND RADIO NOTES SECTION

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Ferdinand Hamburger, Jr.

REGIONAL DIRECTOR, 1950–1951

Ferdinand Hamburger, Jr., Regional Director of the Central Atlantic Region, was born at Baltimore, Md., on July 5, 1904. He was graduated with the degree of Bachelor of Engineering in electrical engineering from The Johns Hopkins University in 1924. After participating in a program of dielectric research for several years, he earned the degree of Doctor of Engineering from that University in 1931. He was a Charles A. Coffin Fellow in 1930–1931.

Dr. Hamburger, who has been on the staff of the electrical engineering department of The Johns Hopkins University since 1931, was appointed professor of electrical engineering in 1947. He served as chief test engineer for Bendix Radio Division from 1942 to 1945 while on partial leave of absence from the University, as Consultant for the NDRC, Section 17-2, during 1944–1945, and as Consultant to the Research and Standards Section, Bureau of Ships, Navy Department during 1945–1946. He is Associate Director in charge of Engineering of the Systems Research contract between The Johns Hopkins University and Special Devices Center, Office of Naval Research, at the present time.

Dr. Hamburger joined The Institute of Radio Engineers as an Associate Member in 1931, and became a Member in 1939 and was elevated to the grade of Senior Member in 1943. He was largely responsible for the formation of the Baltimore Section of the Institute in 1939 and for its reorganization in 1944.

He has served as Chairman of the Section in 1940–1941, and has been a member of its Executive and Meetings and Papers Committees since its inception. Dr. Hamburger has been the IRE representative at The Johns Hopkins University since 1941.

He is also a Fellow of the American Institute of Electrical Engineers, a member of the Societies of Sigma Xi and Tau Beta Pi, and a Director of The Engineers Club of Baltimore. Dr. Hamburger is the author of numerous technical papers.

As long as science was an abstract and remote thing having no substantial relation to everyday living, men in general were willing to leave the nature and effects of science to the ivory-towered scientists.

But now science and its many engineering applications profoundly affect every man, whether he knows it or not. The coolie gathering rice in China may be influenced by the invention of a machine for making breakfast foods in Battle Creek, Mich. A clerk in any city may meet a sudden doom as a result of the discovery of the equivalence of mass and energy and the resulting implications (and atomic-bomb applications) of that startling fact.

Mankind can no longer disregard the scientist. Conversely, the applied scientist can no longer slight human needs, neglect the social consequences of his work, or close his mind to urgently needed expansions of the scientific method.

In the following thoughtful discussion, a necessary first step is proposed to ward off major injury to our civilization in an analysis written by a former Director of the Institute, a member of its Editorial Administrative Committee, and Vice-President in charge of engineering of Sylvania Electric Products Inc. He has suggested a promising line of thought and action.—*The Editor.*

The Reality of Invisible Forces

E. FINLEY CARTER

No one has ever seen a force of any kind. We are too prone to think that our operating devices and activities are forces in themselves, whereas they are only tangible evidence of invisible forces at work. A realization of that fact is needed as a starting point for a fresh consideration of the power of great spiritual forces at work within our human society.

From the viewpoint of the physicist, force may be defined as that which changes the state of rest or motion in matter. Its effect is measured by the rate of change in momentum. Spiritual forces also tend to change the state of rest or momentum, not so much of matter as of events. These are positive as well as negative forces. Their names in our everyday language are love, hate, hope, fear, faith, and despair. They are as difficult to define as electricity and magnetism, but there are many analogies that can be drawn between these forces and the physical forces with which engineers deal. Though we have become accustomed to dealing with great forces, many have not become real to us because we have not learned to know them.

The forces of gravity, electricity, and magnetism were not accepted as real until relatively recently. It has not been long since their manifestations were looked upon with awe and surrounded by superstition. Lightning was the wrath of the gods. Those who dared explore the unknown were often jeered and even persecuted. It took brave men, compelled by faith and conviction, to risk being different in their urge to know the truth. But there were such pioneers who brought forth basic knowledge and who dared to apply it. As a result, the method of invention was born. From invention has sprung the Industrial Revolution, and with it, the engineer as the applied scientist. Just as the Industrial Revolution awaited sound and wide-spread application of the invisible physical forces discovered and defined by the great scientific thinkers, so may a Spiritual Revolution result from the sound application of spiritual forces that have been enunciated and displayed by great thinkers and great lives who have preceded us. Such a revolution is awaiting the applied social scientist or the "human engineer."

The discovery or enunciation of a scientific principle, no matter how profound, is not enough. It must be applied to be effective. The engineer, who has applied the invisible but real physical forces of the universe so effectively during the recent past, can contribute toward the application of the great spiritual forces which inspire one's finer emotions. It is about time that we turn a portion of our thoughts to the seeking of a further understanding in order that we may better apply these great forces which motivate our very existence and govern our relationships with one another. They work on the hearts and wills of men and nothing is accomplished that is not first willed. It is within the province of each of us to devote some time to a better understanding of human relations and of the impact of new scientific developments upon society. Life is becoming increasingly complex. We, as engineers, have helped to make it that way. It is high time that we learn better how to live with our inventions and with each other. We can ill afford to ignore this fact, unless we wish to invite chaos which will make of little real importance the material wonders of our age.

Television—Why the Deep Freeze?*

STUART L. BAILEY†, FELLOW, IRE

FOR MORE THAN fifteen months, the television industry of the United States has been subjected to a freeze which has stopped all action at the Federal Communications Commission directed toward granting additional stations. This paper will discuss the events leading up to the freeze and point out the reason why it was imposed. It will also describe the present situation in Washington where a hearing is being held which will determine the future of the industry.

It is assumed that everyone knows that the allocation of all radio-frequency channels in this country, with the exception of those used by the United States Government, are handled by the Federal Communications Commission. Many also know that allocations to radio broadcast services have raised some of the most difficult questions the Commission has had to answer. For example, with more than 100 channels available for AM broadcasting, the demand has always in the past far exceeded the supply, requiring extended hearings by the Commission to determine the most qualified applicant.

The problems of television allocation are many times greater than those encountered in any other broadcast service due to factors inherent in the service itself. Television is a voracious devourer of space in the spectrum—one black-and-white television channel under the present standards requires a full 6-Mc bandwidth—enough to provide 100 to 150 communication channels. In spite of the best efforts of industry and the Federal Communications Commission, it has not been possible to find room for more than twelve such channels in the entire radio spectrum below 300 Mc.

It is perhaps surprising to know that the space available for television today in the region below 300 Mc is less than that which was available before the war. A little consideration, however, will show that the tremendous growth of services other than broadcasting since the war, particularly the safety and mobile services, has made necessary a shrinking of the television space. This has been accompanied by an increased demand from the military for assignments in this region.

It is not necessary to go backward many years to trace the development of television allocations if we limit ourselves to a study of such allocations which provided for a reasonably high-definition service requiring a bandwidth of several megacycles. It was not until about 1933 that the requirement for a large bandwidth was recognized in allocation proceedings. In 1936, the Commission held an informal engineering conference and, the following year, adopted an order allocating a total of 19 channels to television. All activity at this time was devoted to the development of equipment and experimentation, and this continued until 1939 when the Commission began to receive applications for television stations which contemplated broadcasting to the general public on a commercial basis. After a thorough study, the Commission decided that television broadcasting was still in a developmental stage and that because system standards could not be agreed upon by the industry, the Commission would not adopt any standards at that time.

Late in 1939, the Commission again reviewed the television situation and issued proposed rules which would provide for the licensing of stations to render sponsored programs to the public. Hearings were held on these proposed rules in January, 1940, and these hearings immediately disclosed the fact that there was still a considerable difference of opinion relative to the standards, particularly for line and frame frequencies. The result of this hearing was to keep television in the experimental stage and to point out to industry that the Commission felt that further experimentation was necessary before standards could be adopted which would forever set the quality of very-high-frequency television broadcasting between 30 and 300 Mc. However, certain limited operation with programs was allowed.

In spite of a strongly worded Commission warning in its report on these hearings, the television industry began a large-scale campaign to sell receiving sets to the public. The Commission, feeling that this campaign was designed to force one system of standards by getting many receivers in the hands of the public, took punitive measures by repealing all authorizations for limited program operation.

This action led to the formation of the National Television Systems Committee which was an industry committee formed at the request of the Federal Communications Commission and charged with the responsibility of bringing divergent elements together in an effort to agree on a uniform set of standards. It is greatly to the credit of the industry that it was able to settle most controversial points and that the report of the National Television Systems Committee contained, in most part, the standards which are in use today. These standards were adopted on April 30, 1941, and provided for eighteen commercial channels.

Following the adoption of the rules which, in effect, gave a "green light" to commercial television broadcasting, the building of a nation-wide system was interrupted by the advent of the war. Only five television stations were installed before the war stopped all construction in 1942; and it might be said that these five stations kept television alive during the war. The war restrictions built up a backlog of demand for television assignments, and by the middle of 1945 there were 118 applications for commercial television facilities. In October of that year, the Commission removed the restrictions on new construction, allowing the industry to proceed.

About a year earlier, the Commission realized that it would be necessary to reexamine the entire radio structure anticipating that war developments would cause a tremendous increase in demand for radio facilities throughout the entire spectrum. The fall of 1944 saw the beginning of the most comprehensive proceeding of its kind in the history of radio. Because of the many services to be considered, the Federal Communications Commission requested the Institute of Radio Engineers and the Radio Manufacturer's Association to co-operate in setting up an organization which could present the views of many of the diverse users of radio throughout the country. This resulted in the establishment of the Radio Technical Planning Board which presented testimony on many different subjects at the hearings. The story of the Radio Technical Planning Board and the results it obtained is far too long to discuss here. It recommended that television be assigned eighteen channels between 60 and 218 megacycles, sharing with other services where necessary. I think it is fair to say that its major recommendations concerning allocations for FM broadcasting and television to the Federal Communications Commission in this hearing were not reflected in the Commission's final decision. This final decision allocated but twelve channels to television in the very high frequencies; and after long argument, one additional television channel was found, resulting in thirteen very-high-frequency channels, some of which were to be shared with fixed and mobile services.

On November 21, 1945, the Commission adopted rules governing television allocation; and these rules contained a table showing allocation of television channels to 140 metropolitan districts in the United States. Here, for the first time in the history of broadcast allocations, we encounter the principle of reserving channels for use in certain communities by the procedure of incorporating them in the rules of the Commission. This may seem inconsequential, but I would like to point out that it has a very important bearing on the problems facing us in television allocation today. It means that, by this procedure, the Commission has a plan and this plan cannot be modified without a mechanism known as "rule-making

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† Jansky and Bailey, Washington, D. C.

procedure." For example, if a person finds that it is possible to establish a station in a city and on a channel not provided for in the plan, he cannot file an application for such a facility, but must first request rule-making procedure which will be in the form of a hearing to determine whether the rules shall be modified to provide for the facility in question. Of course, if he is successful in getting the rules modified, it is possible that he still will be faced with a hearing to determine whether he will be the person who finally receives the grant. Important in this consideration is the fact that the Commission is not required to grant a request for rule-making procedure, which could have the effect of arbitrarily denying the applicant his "day in court."

Subsequent to adoption of the rules above referred to, it became apparent that it would not be satisfactory to have mobile and safety services sharing channels with television. Therefore, after another hearing, the Commission deleted Channel 1 from the television list and assigned the frequencies therein to various mobile and safety services, leaving Channels 2 through 13 exclusively for television.

In May, 1948, the Commission proposed the adoption of a new table of allocations, providing outlets in many cities and towns not covered by the original table and at the same time taking into account the deletion of Channel 1. In general this revised allocation attempted to provide at least one outlet in cities and towns having a population of 10,000 and over; and, in fact, approximately 450 such communities were included. This proposed change was made the subject of rule-making procedure, the hearing on which was started in June, 1948; and, while there have been many changes since then, this hearing is still in progress.

Let us go back now and lay the groundwork for the engineering considerations which, of course, must be the basis of any allocation table. At the transmitter, the effective radiated power and the transmitting antenna height must be known. At the receiver, the type of antenna to be employed, its average height above the surrounding terrain, and the noise levels present at the receiver are pertinent factors, as well as the selectivity characteristics which affect the adjacent channel rejection. Between the two we have the propagation medium with all its vagaries, and the effect of this medium on transmission must be determined. In addition to the foregoing, subjective factors must be evaluated which determine the ratio of desired to undesired signals necessary to avoid interference between stations operating on the same and adjacent channels. Many of these factors were fixed, perhaps arbitrarily, by the Commission in establishing its present allocation which, incidentally, is still the one of November, 1945. At the transmitter, the Commission assumed that metropolitan stations would operate with an effective radiated power up to 50 kilowatts at a height of 500 feet above the average surrounding terrain. It was further assumed that the average receiving antenna would be a dipole located 30 feet above the ground and that in rural areas the noise level would be low enough so that good service could be provided with a field intensity of 500 microvolts per meter. Recognizing that noise levels encountered in cities are higher, the rules indicate that field intensities up to 5,000 microvolts per meter might be necessary for service in the larger cities. Propagation factors were determined by supplying charts for various frequencies between 60 and 200 megacycles, which charts were based upon theoretical calculations giving the field intensity versus distance, assuming a smooth homogeneous earth between transmitter and receiver and a so-called standard atmosphere, i.e., one in which the dielectric constant of the air changes progressively outward from the earth's surface in accordance with a standard curve. In addition, the Commission standards provided that a ratio of desired to undesired signals of 100 to 1 was necessary to prevent objectionable interference between stations on the same channel, and that a ratio of 2 to 1 was necessary if the stations were on adjacent channels. Use of all these factors resulted in an average spacing between co-channel stations of 150 miles and between adjacent channel stations of 75 miles. The standards recognize the possible existence of tropospheric effects which would cause interference greater than that predicted by the curves but suggest that a tropospheric curve would be appended to the standards at some later date. This curve was never supplied and, therefore, all proceedings were on the basis of ground-wave consideration only.

During the course of the rule-making hearing which began in June, 1948, it was apparent that the possibility of tropospheric interference could not be ignored and that, for this reason, the service areas predicted by the Commission for its proposed allocation would be smaller than anticipated. At this point, the hearing was halted, and an engineering conference was called in September, 1948, to determine whether sufficient information was available to evaluate the effect of the troposphere as a factor in causing interference. This September conference immediately disclosed the fact that there were very little data which could be used in studying the tropospheric effect and that what were available would require a great deal of study and analysis. Realizing that it would be unsafe to proceed with an allocation which ignored the tropospheric effects, the Commission, about the first of October, 1948, announced that it would freeze all present and future applications for television until such time as a proper study could be made. At this time there were 303 applications pending for television stations, 37 stations were in operation, and construction permits had been granted for 86 more. The announcement of the freeze made it clear that those holding television construction permits would not be prevented from going ahead with construction; and later action of the Commission practically required such stations to proceed even though some may have desired to hold off, awaiting the outcome of the proceedings. At that time it was felt that the freeze could probably be lifted in approximately six months. However, after fifteen months, the freeze is still in force and none of us can foresee when it might be lifted.

During the period of the freeze, there have been some very important changes in many of the factors affecting television allocations, as well as in the thinking of the Commission as to the theory of such allocation. These should be understood in order to realize the difficulty which now faces the Commission and the entire industry. At the time of announcing the freeze, the Commission called another engineering conference for the end of November, 1948, and said that in the intervening time the Commission engineers would study the data and release reports giving their interpretations which could be discussed at the conference. However, the conference disclosed that there were some very serious questions as to the methods used in analyzing the data as well as the results obtained; and at this point an *ad hoc* committee was appointed consisting of representatives from the Federal Communications Commission, the Central Radio Propagation Laboratory, and industry for the purpose of making the necessary study and bringing in a report which could be used as a basis for future allocations. As a member of the *ad hoc* committee I can assure you that the long delay in producing a report of the committee was not due to any lack of effort on the part of the members. They met every week for a period of several months and throughout their deliberation had the full co-operation of industry, the Federal Communications Commission engineers, and members of the staff of the Central Radio Propagation Laboratory. However, the very meager amount of data available for study was appalling to all; and a portion of the delay was caused by the necessity of digging out new sources of information and adding such information from time to time as it became available. The report of the *ad hoc* committee was issued on the last day of May, 1949; and, while every effort was made in the report to point out that the results are only rough approximations, it is probable that the curves contained therein will be used for many years in allocation procedures.

It should be understood that the *ad hoc* committee attempted to limit its activities to the determination of engineering factors necessary to the prediction of service and interference from very-high-frequency stations. It made no attempt to determine how far apart stations should be placed on the same and adjacent channels because it was felt that this involved policy decisions which would have to be made by the Commission. The Commission did, in fact, use the *ad hoc* committee report in preparing its next proposal for television allocations. Before discussing this proposal, two other considerations which have complicated the allocation picture should be reviewed. The first is the possibility of using frequencies well above the present very-high frequencies for a general television broadcast service, and the second is the recurrent proposal that color television should be provided for within the framework of any rules which are adopted at this time.

With respect to the first, members of the Federal Communications Commission have repeatedly stated for several years that it will not be possible to provide a nation-wide competitive television service utilizing the limited number of channels available in the very-high-frequency band, and they have repeatedly emphasized to industry that the only hope of achieving such an end would be to expand into the ultra-high frequencies, specifically to the region between 480 and 920 megacycles which for some years has been set aside for experimental television operation. It is true that much of the Commission emphasis on this region suggested that it might be used for an improved type of service, either color television or high-definition monochrome, and that it is not until recently that the Commission thinking has turned to the possible expansion to these frequencies using the standards now in effect.

There are, of course, many deterrents to the use of these ultra-high frequencies for a broadcast service, some of which may be classed as temporary because they involve the state of the art as regards transmitter and receiver development. Others are less tangible because they admit a general lack of information as to what the actual transmission conditions are at these higher frequencies and whether or not they will be at all suitable for a general broadcasting service. Furthermore, the tremendous expansion of the number of television receivers in the hands of the public makes very difficult an extension of the television service in a part of the spectrum where the present receivers are not at all suitable even when used with converters. Not until the Commission released its latest proposed television allocation on July 8, 1949, did the industry realize that the ultra-high frequencies might have to be incorporated in the present television structure, using the present standards of bandwidth, and that it might be faced with situations where both very-high-frequency and ultra-high-frequency channels would be used in a single community, requiring provision in receivers for the full frequency range. How this happened is largely a matter of conjecture, but I believe it can be explained by a statement which I made at a meeting in Philadelphia in April, 1949. This statement is as follows.

"Many have asked what the probable outcome of these deliberations will be, and I can say that one man's guess is as good as another. I am willing to predict that the next allocation from the Federal Communications Commission will incorporate spacings between stations considerably greater than those which were used in the proposed allocation of May, 1948. I estimate that the co-channel separation will be increased from the old 150 miles to something between 200 and 250 miles and that adjacent channel spacing will be increased in approximately the same ratio. Therefore, the next allocation will provide for fewer outlets in many of the major cities and will probably deny any outlets to certain communities which were covered in the previous allocation. Spokesmen for the Federal Communications Commission have already stated that television should provide a nation-wide competitive service, and it is obvious that any increase in the spacings will make this goal even more difficult to attain than in the past. This will place the Commission upon a most uncomfortable spot, and I think that these same spokesmen have indicated how they expected to get off—namely, by providing for commercial operation with the present standards in part or all of the ultra-high-frequency band between 480 and 920 megacycles. Understand that this does not eliminate the spot. It merely takes the Commission off and places the industry upon it, and I am sure that this spot will be just as uncomfortable for industry as it was for the Commission, unless ways can be found to eliminate it. I hope that if this happens, industry will take up the challenge and bend every effort to a solution of the ultra-high-frequency obstacles which today seem so insurmountable."

This statement was made with no inside knowledge as to what was going on at the Commission, and it is interesting to see that the proposed allocation set forth in the Commission's release of July, 1949, provided for co-channel spacing in the very high frequencies of 220 miles and adjacent channel spacing of 110 miles.

The document of July 8, 1949, announcing the new proposed rules and standards and the new allocation table, is so far-reaching in its import as to merit further study. Time will not permit a detailed explanation, but I will attempt to list those fundamental changes in the theory of television allocations which are important.

As I have said, by this document the Federal Communications Commission proposed to add channels in the ultra-high-frequency region between 480 and 920 megacycles—forty-two channels more, to be exact. Thirty-two of these channels are to be used by so-called metropolitan stations and ten channels by community stations.

The allocation table contained in this document which assigns channels to cities and communities is prepared on a principle entirely new in television planning, that is, that the *first* priority of allocation will be "to provide at least one television service to all parts of the United States." Second in priority is the desire to provide at least one television outlet to each community in the country. The third objective is to provide a choice of at least two television services to all parts of the United States and fourth to provide two outlets to each community. *Here, for the first time in television history, do we have a proposal to give square miles priority over people in the assignment of channels.* This is a most important departure and should be kept in mind throughout the remaining discussion.

Another fundamental change in allocation thinking abandons the use of contours of equal field intensity as definitions of service and substitutes "iso-service" contours, that is, contours along which the probability is equal that a certain percentage of possible receiving locations will receive a stated grade of service for a given percentage of the time. This principle recognizes the fact that propagation in both the very-high-frequency and ultra-high-frequency portions of the spectrum is subject to wide variation with both time and location and that a statistical method of presentation is necessary to a study of the service problem. It must be remembered, however, that our present data are very limited and statistical methods of analysis do not add to the knowledge. This is a fundamental law which is often lost sight of by the practicing statistician. Wiener[1] makes the following statement which should be posted prominently in many Washington offices: ". . . if in a function of several variables we allow some of them to range unimpeded over their natural range of variability, we lose information. No operation on a message [he is speaking of the transmission of information] can gain information on the average. Here we have a precise application of the second law of the thermodynamics in communication engineering." Therefore, the curves used by the Federal Communications Commission to define grades of service, taken as they were from the report of the *ad hoc* committee, are no better than the original information available to that committee. In addition, the Commission by its own assumption has extended the use of the curves to the ultra-high frequencies, an action not contemplated by the *ad hoc* committee.

The result of applying the above-mentioned system of priorities, together with the methods of defining service and interference, is an allocation table assigning television channels to more than 1,400 cities and towns in the United States. Only 200 of these get very-high-frequency channels. The remainder must depend on the development of ultra-high-frequency equipment. The priority system, which has placed first emphasis on square miles, has resulted in assigning channels to more than 800 cities or towns of less than 10,000 people and, in fact, to many towns of less than 1,000 persons. Combining these figures with the knowledge that the assignments contemplate using effective radiated power of 100 kilowatts for very high frequencies and 200 kilowatts or even 2,000 kilowatts for ultra-high frequencies, the conclusion is inescapable that the objective of the first priority requirement will never be realized. However, this priority system is the basis of the plan proposed for the hearing now in progress.

Whether we like it or not, we now come to the role color television is playing in the present situation. Remember that prior to the July 8, 1949, release of the Commission, the space between 480 and 920 megacycles was assigned to *experimental* television and was intended as a place where the industry could try out different standards of transmission, looking toward the development of higher definition monochrome and color. In the fall of 1946, the Columbia Broadcasting System petitioned the Commission for the establishment of color television standards in the ultra-high-frequency band, arguing that they had carried their experiments to a

[1] N. Wiener, "Cybernetics," John Wiley and Sons, Inc., New York, N. Y.; 1948.

point where additional information could be gained only by standardization and subsequent commercial operation. Hearings were held in December, 1946, and January, 1947, following which the Federal Communications Commission decided that it was too early to standardize on color and denied the Columbia petition, thus apparently closing the door on the specter of color for some time. Significantly, much of the opposition to the Columbia Broadcasting System proposal at that time was based on the argument that the ultra-high frequencies were inferior to the point of being useless for the establishment of any television broadcast service.

Little more was heard of color television until 1948 when Columbia, apparently trying to salvage some of their efforts in the field, built some color equipment for a medical supply house and started demonstrations of the practicability of reproducing operating room techniques in color at a distance. The equipment used in these demonstrations departed from the old wide-band requirements and used a frame and line frequency which could be accommodated in a 6-megacycle channel. Of course, the over-all resolution was degraded, but the addition of color made the degradation less noticeable. Aware of these demonstrations and having received some communications from members of Congress indicating that color should be further considered, the Federal Communications Commission invited testimony from those who had experimented with color as follows:

"B. The Commission will give consideration to proposals for a change in Transmission Standards on Channels 2 through 55 looking toward color television or other television systems. Any such proposal shall:

1. Be specific as to any change or changes in the Transmission Standards proposed; and
2. Shall contain a showing as to the changes or modifications in existing receivers which would be required in order to enable them to receive programs transmitted in accordance with the new standards.

C. It is proposed to consider changes in Transmission Standards for Channels 2 through 55 only upon a showing in these proceedings that:

1. Such system can operate in a 6-megacycle channel; and
2. Existing television receivers designed to receive television programs transmitted in accordance with present transmission standards will be able to receive television programs transmitted in accordance with the proposed new standards simply by making relatively minor modifications in such existing receivers."

This release opened up the old color television question again and resulted in appearences at the hearing which have delayed the entire procedure. The interpretation of the last paragraph in the above quotation has been the subject of prolonged argument and has caused the issue of compatibility to become most important. Portions of the industry have defined a compatible system as one in which no changes are necessary in existing receivers to enable them to receive transmissions using the color standards (in black and white), whereas others feel that it is satisfactory to use a new set of standards even though it requires circuit modifications (which might be made by servicemen in the field) in existing receivers.

Two systems have been demonstrated to the Federal Communications Commission to date. The first is the Columbia system which is "field sequential" using 405 scanning lines per frame interlaced two to one, the frame frequency being 48 per second and the field frequency 144 per second. Obviously, these standards would require some changes in the circuits of existing receivers. The second system, developed by the Radio Corporation of America, may be described as a "dot sequential" system employing dot interlacing and which, by a process of electronic sampling, theoretically maintains the resolution of the present black and white standards and at the same time is fully compatible in that it requires no changes in existing receivers if their owners are satisfied to receive black and white reproduction from a station transmitting a color program. A third system, which is to be demonstrated in February, 1950, is one developed by Color Television, Incorporated, which may be described as a "line sequential" system and which apparently is also fully compatible.

The hearing on all of the issues raised in the Commission's new proposed rules and standards was resumed on September 26, 1949; and the order of procedure was such that the first part of the hearing would be devoted to general problems whereas the second portion would cover specific assignments of channels to specific areas. Furthermore, the Commission decided that the color question would be the first general issue to be heard. As a result, there have been weeks of testimony on the subject interspersed with individual and comparative demonstrations, and it is anticipated that this phase will continue at least through February, 1950. Following this, all of the other general issues must be taken up; and thereafter the Commission will hear individuals arguing against or for specific channel allocations. Thus, at the present time, it does not appear that the television freeze can be lifted before late in the fall of 1950 or early in 1951.

There are many opinions as to the effect of such an extended freeze on the television industry, some stating that it is good to call a halt and see where we are going before the system is forever tied to the present standards, while others say that a continued freeze will seriously hurt the industry at a time when it should be growing rapidly. Remember that when further grants were stopped fifteen months ago, only 37 stations were in operation and there were 86 outstanding construction permits. Since that time, practically all of the construction permit holders have completed work, and by the end of 1949, 98 stations were in operation, leaving but a few to open new markets for television receivers or absorb the output of transmitter manufacturers. In the meantime, those who have been able to get on the air are experimenting with program techniques and exploring sources of revenue which may give them a favored position when competitive stations are again authorized.

Summarizing the situation, the television freeze was instigated fifteen months ago, particularly for the purpose of investigating the effect of tropospheric transmission on the predicted service areas of television stations. Since that time, new issues have been raised, particularly a priority system which puts the emphasis on coverage of area rather than population, the usability of the ultra-high frequencies, the definition of service areas on a statistical basis, and a possible change in the standards to provide for the use of color television. All of these add up to a variegated ball of wax which must be molded into some acceptable shape before the industry can proceed. Unfortunately, there is little opportunity to turn back because the issues are so intermixed. At one time it might have been possible to go back to the proposed allocation of May, 1948, and show that the use of palliatives such as off-set carrier and directional receiving antennas would make a usable allocation without the necessity of venturing into the ultra-high frequencies. However, adoption of the priority system would make such a move impossible. It is certain that no single decision can satisfy all, and it is possible that a criterion of a good decision is one which dissatisfies all elements approximately equally. There is no question but what the freeze was necessary. It will remain for posterity to determine whether its long continuance is constructive or destructive.

Reliability in Electronic Equipment*

GILBERT B. DEVEY†, MEMBER, IRE

Summary—**Since the last years of World War II, the use of electronic equipment has come more and more into being. Maintenance and repair techniques have so lagged behind this development that, in the case of military electronics, maintenance costs are sometimes one hundred times the production cost. Motivated by rising costs, the need for safety, and the lack of trained repair personnel, steps are being taken to provide greater reliability in electronic equipment. Using reliability data obtained from effective telephone repeater equipment and other systems, attempts are now being made to effect on-the-spot replacement of faulty subassemblies and to make available better vacuum tubes. Progress has been made with printed wiring components imbedded in plastic compounds. The military, faced with overburdening maintenance problems, production demands in times of mobilization, and untrained personnel, looks to development of greater reliability, inbred into equipment design. At present the military is seeking to have the manufacturer join, with comparable research, into the search for greater reliability. The Office of Naval Research is carrying out a research program in analyzing electronic maintenance minimization.**

SINCE THE LAST years of World War II, the need for improved reliability in electronic equipment has become apparent. Reliability takes into account such factors as over-all cost, maintenance requirements, complexity, frequency of failures, and assembly techniques. The several aspects of reliability have come to the front largely because electronics has matured. Although many modern equipments are assemblies of conventional circuits tailored to perform specific tasks, the rapid growth in quantity use of electronic equipments has outstripped the growth of reliability of equipment performance. Reliability of other engineering achievements is sometimes compared to that of electronic equipments; in the main, such examples as electric refrigerators, motors, alternators, spark plugs, and other obvious examples are very reliable, and failures, if any, can be predicted accurately enough to permit preventive maintenance measures. Only to a limited extent is this possible with electronic equipment.

Extensive repair and maintenance facilities make it possible for the user to have an acceptable performance standard for electronic equipment; this is costly. So expensive is it that an estimate of the maintenance bill, in the case of military electronics, is about ten to one hundred times the cost of the original equipment! So complex are the problems of large volume procurement, test and inspection, transportation, personnel training, spare parts supply, and storage, that a definite monetary estimate is virtually impossible. Although the military is the largest single consumer of electronic products, it is not alone in this problem. Commercial interests have recognized the inadequacy of current standards of construction and are taking steps to rectify present troubles. In many instances, cost is the motivating factor towards more reliable equipment; in other cases the factor of safety is paramount. Consider the hazard to which an airplane is exposed when communication equipment is inoperative, the danger a steamship faces when her radar fails in a heavy fog, the catastrophe possible when an electronic computer controlling a guided missile interceptor falls out of adjustment, and the consternation caused by the infrequent malfunction of traffic signals in a large city. It is here that reliability should be most meaningful. These considerations must demand equipment which can be depended upon in emergency. Those whose primary consideration is maintenance will profit as equipment reliability is increased.

Unfortunately, it is almost axiomatic that the more important the application of electronics, the more complex becomes the equipment needed to fulfill the design and operational requirements. More complex circuitry requires highly trained technicians and expensive test equipment for maintenance and repair. Unless reliability is built into an equipment, it is likely that the burden of maintenance will be out of proportion to the usefulness of the equipment.

Certain electronic equipments have been entirely reliable over a period of years. Outstanding in this respect is telephone repeater equipment where dependable operation without vacuum-tube failure has been reported for years of continuous operation. However telephone equipment is the exception, rather than the rule. More applications of electronics to important control problems in industry are foreseen when dependability reaches a universally acceptable level.

Design data on outstandingly reliable equipments and information from present-day pioneers in reliability research are becoming available and will offer impetus to further endeavor. Progress towards absolute reliability is indicated by several examples of work now under way. Plug-in subassemblies, constructed according to functional units, are a convenient way to insure minimum repair time from a failure. The concept here is for the user to effect on-the-spot replacement of the faulty subassembly by inserting pretested units in the equipment until the faulty unit is found and replaced. The faulty assembly is then returned to a central depot for repair. Although this is not a new idea, it is a convenient way to effect repairs and eliminate the need for an established service facility by the consumer.

Another endeavor towards reliability concerns vacuum tubes. It has been said that vacuum tubes would not be designed for insertion into a socket if they were constructed with the expectation of reliable operation; few tubes are wired into circuits, as they must be replaced. Even guaranteed life tubes are made so that they may be fitted into a socket for convenient removal. Commercial interests, the airlines in particular, and the military services, are taking great strides towards making available reliable tubes. Tube dependability can be increased by employment of mechanical arrangements designed to enable the elements better to withstand shock; better materials can be used for tube elements, cathodes in particular; perhaps constant-voltage heater circuits are demanded in the equipment design to relieve strain from a fluctuating voltage supply, or perhaps a short life-test "run-in period" is necessary. This latter consideration is important, since it is known that a high percentage of tube failures occur in the first few hours of operation. The time necessary for testing each tube will vary according to the type of tube and the operating life guarantee based on a predetermined statistical performance standard.

The remarkable progress in the various ramifications of printed wiring, components imbedded in plastic compounds, and the open wiring concept in subassembly construction has made available new techniques which are applicable to greater reliability.

For the military services two factors are of extreme import: (1) an overwhelming problem of equipment maintenance, and (2) an almost insuperable demand on production facilities of the electronic industry in the event of total military mobilization. These problems facing the military services are acute. Studies show that the caliber of technicians required to service adequately existing electronic equipment under conditions of mobilization is higher than the quantity potentially available to the nation. Nor is it indicated that training of technicians, whatever their intelligence level, can keep in step with the demands for such services. During World War II, it was not unusual to find men with advanced degrees in engineering in the positions of electronic equipment repair men. Unfortunately, although their services could be put to good use in development laboratories or production plants, their abilities had to be exploited in the field. It is not intended to argue that these men should not have been on the scene of battle; their presence was required if the complex electronic equipment was to operate successfully. The point is that electronic equipment might better be built with greater reliability to reduce the need for college-trained technicians. The thousands of men graduated from maintenance schools during the war helped relieve the serious situation, but all too often it was necessary to replace electronic equipment (aircraft equipment in particular) by a completely new equipment, rather than repair the old. Frequently, neither time nor talent was available for repairs or routine maintenance. With the rapid growth of electronics for military purposes, it is evident that much more electronic equipment will be necessary for a possible future war than was required during the last. Each man added to the maintenance staff reduces the supply of combat men. The serious competition for technical personnel in various scientific fields among the highly mechanized branches of the services and industry might be critical.

During World War II the electronic industry rallied to the need and produced the

* Decimal classification: R700. Original manuscript received by the Institute, December 27, 1949.
† Office of Naval Research, Washington, D. C.

necessary electronic material for the Armed Services. Even conservative estimates of requirements for any future emergency show that a prodigious amount of material will be required, an amount which may exceed the ability of an industry expanded under the exigencies of emergency to produce the quantities required as soon as required; that is, to produce according to present concepts of electronic equipment design and construction practices.

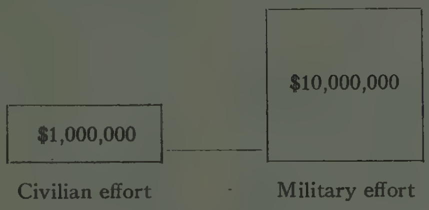
With mechanized assembly processes in use in so many of our industries, it is astonishing that the electronics industry has not adopted automatic equipment assembly techniques to any great extent. Machines can be designed for automatic assembly of equipment and can be made adjustable for diverse applications. Even without complete machine assembly of components, it is possible to employ other automatic processes. For example, telephone switchboards can be wired with wiring automatically pre-formed on a machine and so designed as to seat in appropriate positions on selector switches in a dial system panel; therefore mistakes in assembly are considerably lessened. The adoption of automatic assembly techniques may be essential if production volume is to be achieved and the necessary degree of reliability attained.

The most obvious way to circumvent the manpower and production problems is to strive for greater reliability. Greater reliability of equipment reacts on the equipment availability problem at every point. Fewer men are required to service equipment; thus, fewer men must be trained, thereby freeing thousands to other endeavors. Greater reliability means that the problem of spare parts is diminished; thus, less concern is directed to the very complex problem of provision of warehouse space and transportation (overseas and continental) facilities. Additional numbers of men and quantities of material will therefore be released. Production of spare parts can be cut back; thus, the component parts manufacturer is relieved of a burden. (This consideration is based on a single unit of electronic equipment. More and more applications of electronic equipment will necessitate a very high volume of production.)

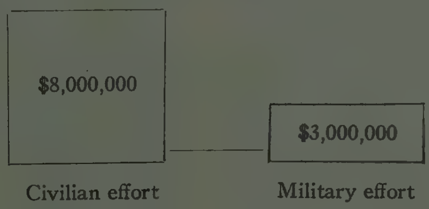
The military worth of electronic equipments, measured in terms of reliability, is more important than the factor of cost alone. A chain is as strong as its weakest link; electronic equipment is as useful as its reliability factor. A long-range radar equipment, costly and complex, has no kinetic military worth when out of operation, undergoing repair. Contrariwise, a short-range equipment of potentially limited military worth is valuable if it is operable when needed.

There are several ways in which reliability can be achieved. The first, and preferable way, is to inbreed reliability into equipment design; this is a direct approach to the problem. The second, that which is attempted today, is to effect preventive maintenance and repairs as necessary; this is an indirect, and failing, approach to the problem. A third attack at the problem would be to provide duplicate equipment for use when the primary system fails; this, of course, is very impracticable.

Consider the situation when $1,000,000 is expended in electronic equipment procurements. It has previously been indicated that the cost of maintenance is at least tenfold more than the acquisition cost. A convenient way to indicate over-all effort is to employ a dollar volume figure. In the case of the $1,000,000 procurement, there is a simple relationship between supplier (the electronic industry) and the consumer (the military services). This relationship can be represented as indicated in the diagram below.



Without investigating the complexities involved in ascertaining effort expended in the above illustration, a conservative figure would be as indicated, 10 parts military endeavor to 1 part civilian. As with the conservation of energy, the total expended effort remains constant. However, a shift of emphasis in endeavor will pay dividends. Suppose that the effort could be divided as shown in the diagram below.



By shifting a larger portion of the total effort to the manufacturer, the problem facing the military is greatly reduced. This is not a selfish desire to place a load on other shoulders. Military worth of equipment is measured in the field; shift of the maintenance load to the manufacturer reflects back to the field in the form of the required reliability. The manufacturer is better able to cope with the problems attendant to equipment design than is the military able to cope with the now unwieldy problem of maintenance and repair.

Obviously the problem of induction deferment of technical and scientific personnel must be solved, if the supplier is to furnish this reliable equipment. Highly trained personnel are necessary in the production of reliable electronic equipment, and they must be available to a manufacturer in time of emergency. Reliable equipment must be designed now to prove that highly trained technical and scientific personnel are not needed on a battle field as has been true in the past.

Certain considerations are indicated if a program of equipment reliability is to be prosecuted. It is first necessary to consider that the use to which equipment is put usually dictates the reliability required. A radar equipment used aboard an aircraft should have a reliable maintenance-free life comparable to the average useful life of that aircraft. A guided missile, on the other hand, requires a short operating life and a long shelf life.

It is seen, therefore, that the length of maintenance-free operating life will vary according to equipment application. The important thing is that a *guaranteed* period of *maintenance-free* operation be provided during which time the only checks required will be of the "go—no go" variety, capable of being carried out by a person trained in nothing but the rudiments of electronics. If this can be achieved, the contribution to efficiency will be profound.

Although the cost and volume of procurement may be increased considerably over present values, this additional outlay could be doubled or tripled, and the total savings would still be impressive when one again considers that present maintenance costs are from 10 to 100 times the acquisition cost of the equipment itself! Even though more money, time, and men are needed per unit to construct reliable electronic equipment, the decrease in quantity production for any one application because of increased reliability will easily make it profitable. Furthermore, the equipment will be in operation when needed in an emergency.

Much effort is yet to be expended before the necessary reliability is achieved. Certainly, nothing less than a radical engineering solution, backed up by research, development, and test information of new components, will bring about the desired results. A change in specification philosophy may be indicated. Perhaps it is not necessary to delineate the specifications of components that go into an equipment; a performance-life test of the equipment itself may be indicated. New testing procedures will have to be devised to determine if a production run of equipments will provide the reliability required by the specification. Many other technical considerations must be coped with if guaranteed reliability is to be realized.

The Office of Naval Research is prosecuting a "Program Analysis in Electronic Maintenance Minimization." Through published findings of this program, it is hoped that laboratories and development activities will more than before realize the importance of electronic equipment reliability, and that endeavors towards absolute reliability will be accelerated. Certainly, the anticipated results will be of mutual benefit to the military services and to the electronics industry in general.

Recent Applications of Electron Multiplier Tubes*

JAMES S. ALLEN†

Summary—**Recent applications of the electrostatic, electron multiplier tube to problems which require the measurement of very small currents or the counting of single ions or electrons are described in this paper. The characteristics of secondary electron emitting surfaces suitable for use in multiplier tubes are discussed in the first section. The next section is devoted to recently developed tubes having one or more stages of electron multiplication. Following this is a section dealing with the application of these tubes to problems involving electron and ion counting. The paper is concluded by a section on the statistical treatment of the distribution in pulse sizes from multiplier tubes.**

I. Introduction

THE SECONDARY electron multiplier is an electronic tube in which the amplification of the initial current of electrons or ions results from electron multiplication at one or more electrodes having secondary to primary electron ratios greater than unity. This type of tube has appeared in many designs and modifications. Although there have been a number of attempts to include one or more stages of electron multiplication in a conventional amplifier tube, this has not proved to be entirely successful. The most widely used multiplier tube at present is the photomultiplier which contains a photocathode and one or more stages of electron multiplication. The special properties and characteristics of this type of multiplier tube have been discussed in reviews by various authors.[1–5]

Bay[6,7] and Allen[8–11] have shown that multiplier tubes may be used directly as particle counters. In this application the primary particle ejects secondary electrons from the first electrode of the tube and these are multiplied at additional electrodes and finally are recorded by suitable counting circuits. This type of particle counter has proved to be nearly 100 per cent efficient as a detector of positive ions and low energy electrons. However, the efficiency for the detection of high-energy beta particles and gamma-rays usually is considerably lower than that of a Geiger counter. An extremely promising technique for the detection of energetic particles has been developed by Kallman,[12,13] Coltman and Marshall,[14] and others. In this application, part or all of the energy of the incident particle is converted into light in a fluorescent screen placed in front of the photocathode of the photomultiplier. Preliminary tests have indicated that when a suitable phosphor has been chosen, the fluorescent counter is a highly efficient detector of high energy beta-particles and gamma-rays.

Since the technical applications of electron multiplier tubes have increased rapidly during the last two or three years, only the most recent developments in the special techniques and properties associated with these tubes will be discussed in this review. The literature on the earlier developments in this field is extensive and, for more detailed information, the reader is directed to the reviews listed in the references given in this paper.

II. Secondary Electron Emission

A. General

Since the operational characteristics of a multiplier tube depend to a large extent upon the type of secondary electron emitting surface surfaces adopted for the multiplying electrodes, a description of certain technical aspects of secondary electron emission will be given in this section. The standard reference on the subject up to 1936 is a review by Kollath.[15] A more recent publication in book form by Bruining[16] deals with the subject up to 1941. Additional sources of information on secondary electron emission are given in the list of references.[17]

We shall adopt a rather general definition of secondary electron emission from a solid. Whenever a solid is bombarded with a beam of primary particles, electrons will be emitted from the surface of this solid. The emitted electrons will be referred to as secondaries. In particular, the secondaries with energies less than 50 electron volts are most effective in the operation of a multiplier tube. In this review the following abbreviations will be used:

* Decimal classification: R339×535.38. Original manuscript received by the Institute, January 9, 1950.

† University of Illinois, Urbana, Ill.

[1] V. K. Zworykin, G. A. Morton and L. Malter, "The secondary emission multiplier—a new electronic device," Proc. I.R.E., vol. 24, pp. 351–375; March, 1936.

[2] G. Weiss, "Über Sekundärelectronen Vervielfacher," *Zeit. Tech. Phys.*, vol. 17, pp. 623–629; 1936.

[3] V. K. Zworykin and A. J. Rajchman, "The electrostatic electron multiplier," Proc. I.R.E., vol. 27, p. 558; September, 1939.

[4] J. R. Pierce, "Electron multiplier design," *Bell Lab. Record*, vol. 16, p. 305; 1938.

[5] W. H. Rann, "Amplification by secondary electron emission," *Jour. Sci. Inst.*, vol. 16, pp. 241–254; 1939.

[6] Z. Bay, "Electron multiplier as a counting device," *Nature*, vol. 141, p. 284; 1938. Also, vol. 141, p. 1011; 1938.

[7] Z. Bay, "Electron multiplier as an electron counting device," *Rev. Sci. Inst.*, vol. 12, pp. 127–133; 1941.

[8] J. S. Allen, "The detection of single positive ions, electrons and photons by a secondary electron multiplier," *Phys. Rev.*, vol. 55, pp. 966–971; 1939.

[9] J. S. Allen, "The X-ray photon efficiency of a multiplier tube," *Rev. Sci. Inst.*, vol. 12, pp. 484–488; 1941.

[10] J. S. Allen, "Improved electron multiplier particle counter," *Rev. Sci. Inst.*, vol. 18, pp. 739–749; 1947.

[11] J. S. Allen, "Particle detection with multiplier tubes," *Nucleonics*, vol. 3, pp. 34–39; 1948.

[12] H. Kallman, "The counting of high energy particles and quanta by photoelectric detection of individual light flashes in fluorescent materials," *Natur und Technik*, July, 1947.

[13] H. Kallman, "Quantitative measurements with scintillation counters," *Phys. Rev.*, vol. 75, pp. 623–626; 1948. M. Blan and B. Dreyfus, "The multiplier tube in radioactive measurements," *Rev. Sci. Inst.*, vol. 16, pp. 245–248; 1945. R. Sherr, "Scintillation counter for the detection of α-particles," *Rev. Sci. Inst.*, vol. 18, pp. 767–770; 1947.

[14] J. Coltman and F. Marshall, "The photomultiplier radiation detector," *Phys. Rev.*, vol. 72, p. 528; 1947.

[15] R. Kollath, "Sekundärelectronen-emission fester Körper," *Phys. Zeit.*, vol. 38, pp. 202–224; 1937.

[16] H. Bruining, "The Secondary Electron Emission of Solids," Springer, Berlin, 1942.

[17] J. H. Owen Harries, "Secondary electron radiation," *Electronics*, vol. 17, p. 100; 1944. "Industrial Electronics References Book," pp. 26–29, John Wiley & Sons, Inc., New York, N. Y., 1948. "Advances in Electronics," pp. 66–120, Academic Press, 1948.

SE = Secondary electron emission
m = The average number of secondary electrons divided by the total number of primary particles
V_p = Energy of the primary particles, assumed to be mono-energetic, in electron volts.

B. Energy Distribution of Secondary Electrons

Although many measurements have been made of the energy distribution of the secondary electrons emitted from solids, it is difficult to estimate the accuracy of these results because of the absence of data regarding the condition of the surface of the solid. However, the general form of the distribution curve for $20 < V_p < 1{,}000$ electron volts is very nearly the same for all the surfaces which have been investigated. It is found that the great majority of the electrons are emitted with energies of a few electron volts. These are usually regarded as "true" secondaries. The shape of this part of the curve is similar to a Maxwellian distribution in which the most probable secondary electron energy ranges from about 2 to 6 electron volts for various surfaces. In general, the peak of the energy distribution is lower for insulators than it is for conductors. The additional features of the complete distribution curve include a small group of inelastically reflected primaries with energies merging with those of the "true" group and extending rather uniformly out to energies nearly equal to V_p. Finally, there is a sharp peak corresponding to elastically reflected primaries. The ratio of the elastically reflected to low energy secondary electrons increases rapidly with the energy of the primaries for $V_p > 1{,}000$ electron volts.

The curves obtained by Kollath[18] will serve as examples of typical energy distributions. In this experiment the analysis of the momenta of the secondaries was made by means of a longitudinal magnetic field. The beam of primary electrons was parallel to the direction of the magnetic field and, consequently, was not deflected.

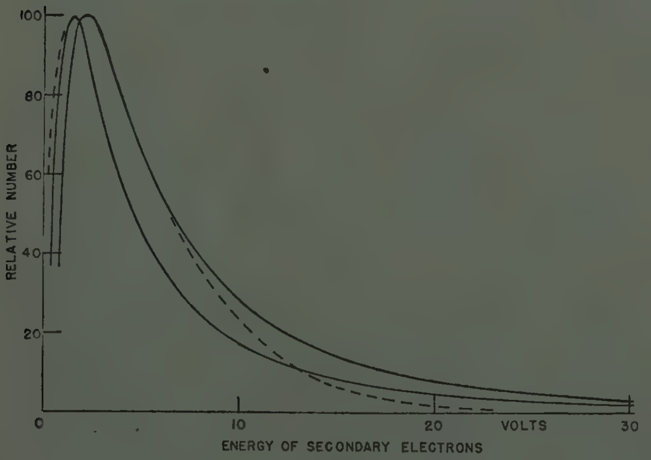


Fig. 1—Energy distribution curves as obtained by Kollath[18] for secondary electrons emitted from various solids. The measured curves fell between the two solid curves. The broken curve represents a Maxwellian distribution.

However, by means of suitable apertures, all secondaries emitted within a certain cone entered the analyzer. Since this arrangement is equivalent to the well-known long lens beta-ray spectrograph, the momentum of the secondaries corresponding to a given value of the magnetic field can be determined from the geometry of the apparatus and the strength of the field. It was found that the general shape of the energy distribution curves was the same for all the metals which were investigated. The results are illustrated in Fig. 1 where the relative number of secondaries per unit energy interval is plotted against the energy. All the distribution curves fell between the two solid curves with maxima at 1.4 and 2.2 electron volts, respectively. The broken curve represents the plot of a Maxwellian distribution with a maximum at 1.75 electron volts. The shapes of the distribution curves showed only minor changes, as V_p was varied from 100 to 1,000 electron volts. However, in the case of BeCu and BeNi alloys, there was some evidence of a secondary maximum at about 5.5 electron volts.

C. SE Yield Due to Primary Electrons with $V_p < 5{,}000$ Electron Volts

In this section the properties of various surfaces having large values of m and therefore suitable for use in multiplier tubes will be described. Since the maximum value of m for a given surface depends to a large extent upon the activation of the sample, large discrepancies exist in the tabulated values of the secondary electron yield. The nature of the activation depends upon the particular surface employed. Usually, a combination of oxidation and heat treatment in a high vacuum will increase the value of m.

The shapes of the m versus V_p curves for $V_p < 5{,}000$ electron volts are essentially the same for both conductors and insulators. In general, the value of m increases with increasing V_p, goes through a broad maximum and then slowly decreases as V_p is further increased. In the case of metal surfaces the value of V_p corresponding to the maximum of m varies from about 100 to 800 electron volts. However, for insulators the maximum usually occurs at much higher-values of V_p. A very qualitative explanation is that the average range of the secondaries is much greater in insulators than in conductors, since there are relatively few conduction electrons to which they can lose energy. Hence, the higher energy primaries are more effective in releasing secondaries in insulators than in conductors.

In Fig. 2 are shown the m versus $-V_p$ curves for two activated composite surfaces and, for comparison, the curve for an oxide free nickel surface.[19] The complex Cs surface has been widely used in photomultiplier tubes for both the photosensitive cathode and the multiplying electrodes. A photocathode may be formed by oxidizing a sheet of silver until the thickness of the layer of silver oxide is several hundred molecules. If cesium vapor is then admitted, it will be completely absorbed by the

[18] R. Kollath, "Zur Energieverteilungen der Sekundärelectronen," *Ann. Phys.*, vol. 1, pp. 357–380; 1947.

[19] R. Warnecke, "Émission secondaire de métaux purs," *Jour. Phys. Radium*, vol. 7, pp. 270–280; 1936.

silver oxide. When the surface is heated at a temperature of 250° C a reaction takes place between the silver oxide and the cesium giving cesium oxide and free silver. Some excess cesium is absorbed on the surface of the complex layer and a sensitive photoelectric surface results. Zworykin, Morton, and Malter[1] and also Timofeev and Pynatnitski[20] have shown that the amount of free cesium required for the highest secondary electron yield is less than that needed for the maximum photosensitivity. An alloy consisting of about 2 per cent magnesium and the rest silver can be activated by radiofrequency heating in an atmosphere of O_2. The curve for this alloy in Fig. 2 was obtained by Zworykin, Ruedy and Pike.[21] The maximum value of m obtained as a result of the activation was about 9.5. However, the multiplication slowly decreased with time and finally reached a stable value of 7 at $V_p=400$ electron volts. Friedheim and Weiss[22] have been able to activate MgAg alloy surfaces by heat treatment at a temperature of 450° C at a pressure of 7×10^{-5} mm of Hg. A multiplication of 14 to 16 at $V_p=500$ electron volts was observed.

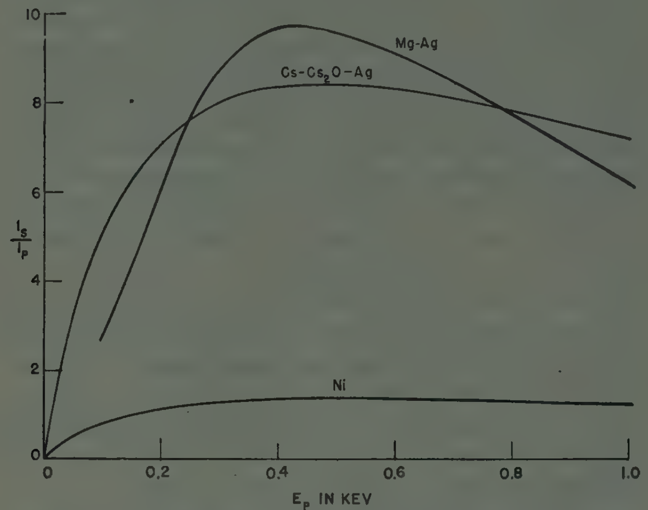


Fig. 2—SE yield curves for MgAg,[21] Cs—Cs_2O—Ag,[1] and oxide free Ni[19] surfaces.

Gille[23] and Matthes[24] have studied BeNi and BeCu alloys. In the case of BeNi a multiplication of 5 or 6 could be obtained by heating the alloy to 600°C in a vacuum at a pressure of 10^{-5} to 10^{-6} mm of Hg. A further increase in the multiplication to a value of 10 occurred after a combination of oxidation and heat treatment. A similar activation of BeCu at a temperature of 500° C resulted in a multiplication of 10 or more.

[20] P. V. Timofeev and A. L. Pyatnitski, "Die Sekundärelectronenemission Einer Sauerstoff Cäsiumelectrode," *Phys. Z. Sowjetunion*, vol. 10, pp. 518–530; 1936.

[21] V. K. Zworykin, J. E. Ruedy, and E. W. Pike, "Silver-magnesium alloy as a secondary electron emitting material," *Jour. Appl. Phys.*, vol. 12, pp. 696–698; 1941.

[22] J. Friedheim and J. G. Weiss, "Sekundäremission ausbeute von Silber—Magnesium ligierungen," *Naturwiss*, vol. 29, p. 777; 1941.

[23] G. Gille, "Die Sekundärelectronen von Nickel-Beryllium Legierungen," *Zeit. für Tech. Phys.*, vol. 22, pp. 228–232; 1941.

[24] I. Matthes, "Untersuchungen über die Sekundärelectronenemission von verschiedenen Legierungen," *Zeit. für Tech. Phys.*, vol. 21, pp. 232–236; 1941.

The curves illustrated in Fig. 3 represent data obtained by the author for the secondary electron (SE) yield from a sample of commercial BeCu. A strip of the alloy was polished with 4/0 emery polishing paper, washed with a detergent and distilled water and finally rinsed several times in ethyl alcohol. Curve 1 represents the multiplication of the freshly polished strip before heat treatment. Curves 2 and 3 show the multiplication after heat treatment. Activated BeCu surfaces may be exposed to air without a serious decrease in the multiplication. For example, the maximum multiplication of the surface shown by curve 3 was 5.7 after a one hour exposure to air and 5.3 after an exposure of two hours. This alloy is suitable for the electrodes of a multiplier tube since a relatively stable multiplication may be attained with negligible thermionic emission at room temperature.

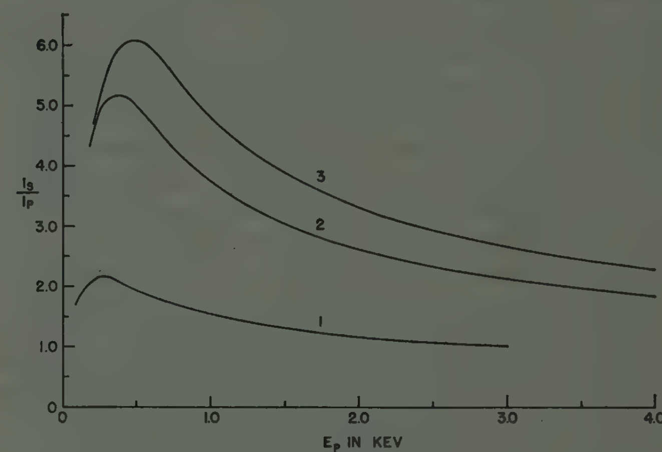


Fig. 3—SE yield curves for BeCu: (1) in the unactivated state; (2) after rf heating for 15 minutes at 650°C in a vacuum; (3) after rf heating at 650°C for 30 minutes in dry oxygen at 5×10^{-2} mm of Hg, followed by the activation described in (2). (From unpublished results of the author.)

D. Variation of the SE Yield with the Angle of Incidence of Primary Particles

The SE yield measurements described in the previous section were made with the beam of primary electrons normal to the surface under investigation. Since the primaries do not impinge upon the electrodes at normal incidence in most multiplier tubes, the variation of the SE yield with this angle is of importance in the design of the electrode system. A number of investigators have examined the variation of the SE yield with the angle of incidence and have concluded that the yield is approximately proportional to $1/\cos\theta$ where θ is the angle between the beam of primaries and the normal to the surface. A qualitative explanation of this relation can be found if we assume that the average range of the primaries in the target is greater than that of the secondaries and also that the rate of production of secondaries is independent of the energy of the primaries. With these assumptions, the fraction of the range of the primaries which is effective in ejecting secondaries from the surface can be shown to be proportional to $1/\cos\theta$. Like-

wise, the variation in yield should be nearly independent of the angle of incidence for low energy primaries where the range may be less than that of the secondaries. These relations have been verified experimentally by Bruining[25] and also by Muller.[26] The curves shown in Fig. 4 were reproduced from the work of Muller and

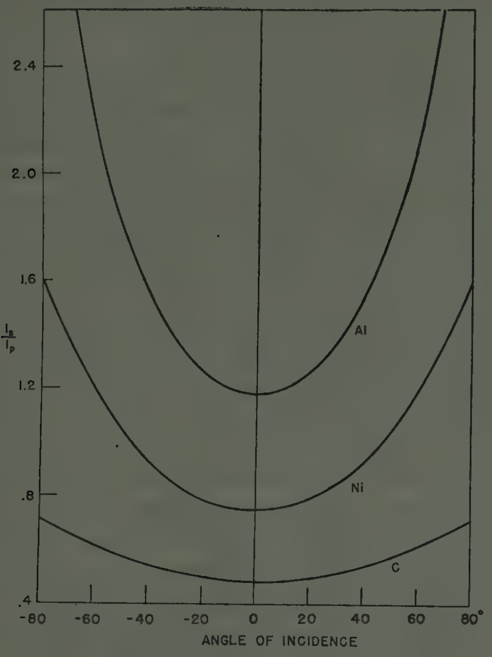


Fig. 4—Variation of SE yield with the angle of incidence made by the primary beam. The energy of the primary electrons was 2.5 Kev (after Muller[26]).

represent the variation of the SE yield with the angle of incidence for several surfaces. The energy of the primary electrons was 2.5 Kev for these measurements.

The author[27] has investigated the variation of the SE yield with the angle of incidence for 120 Kev protons on a nickel surface. The yield followed a $1/\cos\theta$ law for $5° < \theta < 65°$. In this experiment the conditions were favorable for a $1/\cos\theta$ relation, since the range of the primaries was much greater than that of the secondaries and the rate of production of the secondaries was very nearly constant along the effective path of the primaries in the nickel.

E. SE Yield Due to High-Energy Electrons

The information regarding the SE yield due to electrons with $V_p > 10$ Kev is very meager. The interpretation of the results obtained with high-energy primaries is complicated by the presence of a relatively large number of elastically scattered primaries. In practice, the presence of these high-energy electrons may introduce large errors in the measurement of the primary and secondary currents. Stehberger[28] has measured the proportion of high energy secondaries emitted from a gold target. The relative number of high energy secondaries increased from 20 to 48 per cent as V_p increased from 1 to 11 Kev.

Trump and Van de Graaff[29] have investigated the SE yield from various surfaces using mono-energetic electrons accelerated by an electrostatic, high voltage generator. A replot of their results is shown in Fig. 5. The

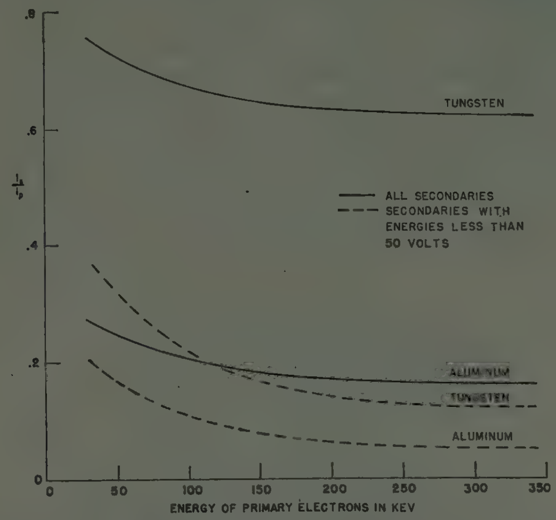


Fig. 5—SE yield curves for tungsten and aluminum surfaces bombarded with high energy electrons (after Trump and Van de Graaff[29]).

yield of low energy secondaries decreases with increasing V_p and remains essentially constant for $V_p > 250$ Kev. According to these curves, an electron multiplier should show a counting efficiency of from 5 to 10 per cent when 250 Kev electrons are allowed to strike the first electrode.

F. SE Yield Due to Positive Ions and Neutral Atoms

In this section information regarding SE yields due to positive ions will be presented. These data should indicate the performance of an electron multiplier tube when used either to amplify a current of positive ions or to count single ions.

Healea and Hontermans[30] have investigated the SE yields due to H_2^+, D_2^+, He^+, Ne^+ and A^+ ions bombarding an outgassed nickel target. In each case the curves indicated an almost linear increase in the SE yield with the energy of the ions in the range from 0 to 1,500 electron volts. A yield of one electron per ion was observed for 1,500 electron volts He^+ ions.

Hill, Buechner, Clark, and Fisk[31] have measured the SE yields from various metals bombarded by high energy positive ions. Curves 2 and 4 of Fig. 6 represent the

[25] H. Bruining, "The depth at which secondary electrons are liberated," *Physica*, vol. 3, pp. 1046–1052; 1936.

[26] H. O. Muller, "Die Abhangigkeit der Sekundärelectronenemission einiger Metalle vom Einfallswinkel des primären Kathodenstrahls," *Zeit. für Phys.*, vol. 104, pp. 475–486; 1937.

[27] J. S. Allen, "The emission of secondary electrons from metals bombarded with protons," *Phys. Rev.*, vol. 55, pp. 336–339; 1939.

[28] K. H. Stehberger, "Über Rückdiffusion und Sekundärstrahlung mittelschneller Kathodenstrahlen an Metallen," *Ann. Phys.*, vol. 86, pp. 825–863; 1928.

[29] J. G. Trump and R. J. Van de Graaff, "Secondary emission of electrons by high energy electrons," *Phys. Rev.*, vol. 75, pp. 44–45; 1949.

[30] M. Healea and C. Houtermans, "Relative secondary electron emission due to He, Ne, and A ions bombarding a hot nickel target," *Phys. Rev.*, vol. 58, pp. 608–610; 1940.

[31] A. G. Hill, W. W. Buechner, J. S. Clark, and J. B. Fisk, "Emission of secondary electrons under high energy positive ion bombardment," *Phys. Rev.*, vol. 55, pp. 463–470; 1939.

data obtained by these authors for H^+ and He^+ ions on a molybdenum surface not previously outgassed. Curves 1 and 3 show data obtained by Allen[27] for H^+ ions on outgassed targets of nickel and beryllium. The effect of absorbed gas on the SE yield can be estimated from a comparison of curves 1 and 2. Apparently, the effect of the gas is greatest for the low energy primaries and is not series for energies greater than 400 Kev.

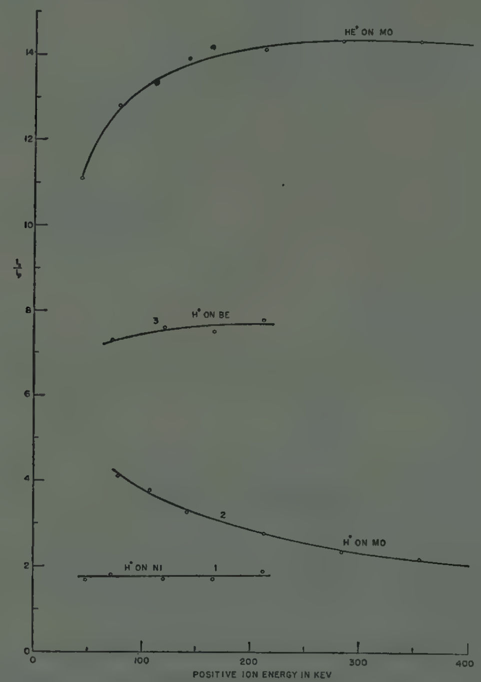


Fig. 6—SE yield curves for high energy positive ions. Curves 1 and 3 from the work of Allen.[27] Curves 2 and 4 from the work of Hill[31] and co-workers.

Berry[32] has recently shown that fast neutral atoms will eject secondary electrons from a metal target. When a beam of either He or A atoms or N_2 molecules was allowed to bombard a tantalum target, the SE yield in each case increased with the energy of the primary particles in the range from 0 to 4 Kev. At the highest energy the yield was about 2 to 3 electrons per neutral particle. This value was almost identical with that obtained for singly charged ions of these same gases.

III. Electron Multiplier Tubes

A. Electrode Surfaces

Electron multiplication has been extensively used as a method of amplification of the current from a photocathode. Since both the photocathode and the multiplying electrodes are located in the same tube envelope, the photoelectric and multiplying surfaces usually are of the same material. The earliest photomultipliers had composite Cs-Cs_2O-Ag surfaces which are frequently given the designation S-1. The spectral response of a typical S-1 surface in a tube with a lime glass envelope has a maximum sensitivity at 8,000 Å and a long wavelength limit of 12,000 Å. According to Fig. 2, the SE yield for this surface should be about 5 for $V_p = 200$ electron volts. The relatively large thermionic current from this type of surface is a serious disadvantage when the phototube is to be used to measure very low light levels. The measurements of Engstrom[33] indicate a thermionic current from the cathode of 10^{-12} to 10^{-11} amperes at room temperature.

In recent years a photosurface formed from a cesium antimony layer on a nickel base has been widely used in photomultipliers. This type of surface is often designated as S-4 and is characterized by a maximum sensitivity at 4,000 Å and a long wavelength limit at 7,000 Å. Presumably, the secondary electron properties of this surface are similar to those of the Cs-CsO_2-Ag surface. In general, the dark current is of the order of 10^{-14} ampere per cm² at room temperature. In addition, the S-4 surface is more stable in respect to the photoelectric and SE yields than the S-1 surface.

Bay[7] and Allen[10] have shown that high work function surfaces can be used in multiplier tubes designed for particle counting. The thermionic emission from these surfaces at room temperature is of the order of 10 electrons per minute per cm². At present, BeCu, BeNi, and BeAg alloys seem to be the most suitable materials for the electrodes. SE yield curves for a sample of commercial BeCu alloy have been given in Fig. 3. Additional details concerning the method of activation and the stability of BeCu surfaces have been discussed by Allen.[10]

B. Photomultiplier Tubes

The subject of photomultiplier tubes has been covered in reviews by numerous authors. For a survey of the developments in this field up to 1941 the reader is referred to papers by Zworykin and Rajchman,[3] Rann,[5] and Glover.[34] In order not to repeat too much of the material covered in these reviews, this section will be limited to a description of the characteristics of several recently developed tubes.

The RCA-931A tube is an example of a photomultiplier utilizing two dimensional, electrostatic fields. The electrodes in the multiplier section of this tube form a series of electron optical lenses which prevent the electron beam from diverging during the multiplication process. The rubber membrane model described by numerous authors[34,35,36] has proved to be a convenient method for the determination of the correct shapes for the electrodes in this type of tube. This method is based upon the analogy between the path of a spherical ball rolling on a suitably stretched rubber sheet and that of a charged particle moving in an electrostatic field.

[32] H. W. Berry, "Secondary electron emission by fast neutral molecules and neutralization of positive ions," *Phys. Rev.*, vol. 74, p. 848; 1948.

[33] R. W. Engstrom, "Multiplier tube characteristics; application to low light levels," *Jour. Opt. Soc. Amer.*, vol. 37, pp. 420–431; 1947.

[34] A. M. Glover, "A review of the development of sensitive phototubes," Proc. I.R.E., vol. 29, pp. 413–423; 1941.

[35] P. H. J. A. Kleynen, "The motion of an electron in two-dimensional electrostatic fields," *Philips Tech. Rev.*, vol. 2, pp. 338–345; 1937.

[36] O. H. Schade, "Beam power tubes," Proc. I.R.E., vol. 26, pp. 137–181; 1938.

The model is constructed by placing on a horizontal surface portions of cylinders whose directrices are similar to those of the electrodes under investigation. The vertical heights of the cylinders are made proportional to the potentials of the corresponding electrodes. A rubber membrane, previously stretched over a frame, is then pressed down on the model in such a manner that the sheet makes contact with the top edges of the cylinders. The paths followed by balls rolling on this membrane approximate rather closely the actual electron trajectories in the electrostatic fields. Hence, the shape of the model electrodes can be modified until the balls leaving a given electrode converge to a reasonably good focus on the next. The dimensions of the model can then be scaled down to fit the requirements of the actual electrode system.

A diagram of the electrode system of the 931-A tube is shown in Fig. 7. Multiplication occurs at electrodes 1 through 9. The final collector is a grid shielded by the ninth electrode. A shield serves to isolate the photocathode from the final collector in order to reduce the danger of positive ion feedback. The sensitive surfaces of the photo-cathode and electrodes 1 through 9 are of cesium antimony alloy. Data concerning the multiplication and spectral sensitivity of this type of tube are listed in the manufacturer's handbooks and also in papers by Engstrom,[33] Glover,[34] and by Glover and James.[37]

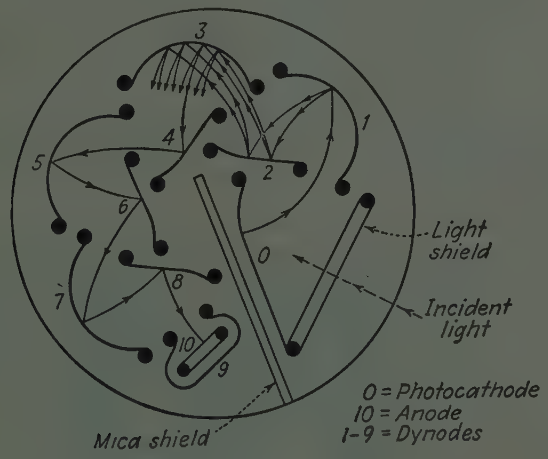


Fig. 7—Schematic arrangement of the electrodes in a 931-A photomultiplier tube.

The so-called dark current in a photomultiplier tube originates in the following sources: ohmic leakage over the insulators inside the tube and between lead wires at the tube base; field-enhanced emission and thermionic emission from the photocathode; and positive ion feedback. The curves of Fig. 8 have been reproduced from the work of Engstrom[33] and show the relative importance of the various sources of the dark current in a tube of the 931-A type. It is evident that the amplified thermionic emission increases more rapidly with the voltage per stage than does the ohmic leakage. In practice, the tube is operated in a region of the characteristics such that the current due to thermionic emission is the predominating factor. In general, this current can be reduced by refrigeration of the tube. The unstable region beginning at 110 volts per stage is due to regenerative positive ion feedback between the photocathode and the last few multiplying electrodes. This effect increases with the residual pressure in the tube and may become so large as to maintain continuous oscillations within the electrode system. The presence of positive ion feedback can be easily detected when the dark current pulses are viewed on a scope with a triggered sweep. If positive ion feedback is present, multiple pulses consisting of the initial pulse followed by one or more secondary pulses will be observed. The pulses will be separated by intervals of the order of 10^{-7} seconds.

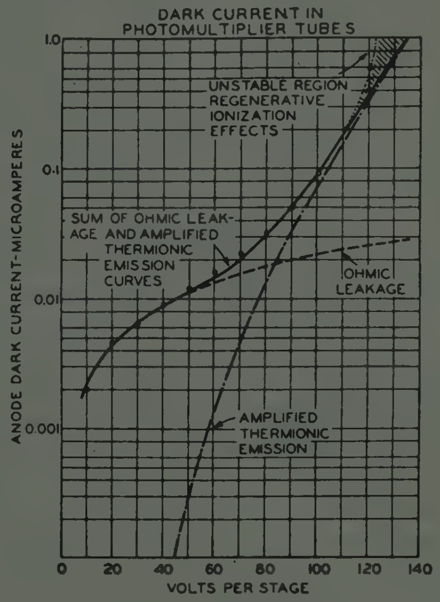


Fig. 8—Dark current in photomultiplier tubes of the 931-A type (after Engstrom[33]).

An electrode structure resembling a venetian blind has been developed in several laboratories. This structure is well suited for use in photomultiplier tubes with large area photocathodes. Fig. 9 shows the schematic arrangement of the venetian blind electrodes used in the E.M.I. type Vx 5031 tube. This tube was developed by A. Sommer and W. E. Turk of the E.M.I. laboratories. The individual slats of the blind structures are of stainless steel or nickel and are coated with an antimony cesium layer. No interstage focusing lens is employed, but each electrode has attached to its front surface a low shadow ratio mesh which serves to prevent the suppression of secondary electrons by the preceding negative field. The secondaries are, therefore, influenced only by the positive field of the following stage and are accelerated through between the slats, and themselves undergo multiplication at the next electrode.

The Vx 5031 has a flat end window with a transparent cesium antimony photocathode 1.0 cm in diameter on

[37] A. M. Glover and R. B. Janes, "A new high sensitivity photosurface," *Electronics*, vol. 13, pp. 26–27; 1940.

the inner surface. The sensitivity of the photosurface is 20 to 30 microamperes per lumen. The eleven stages of multiplication produce a total multiplication of from 10^7 to 10^8 with 160 volts per stage.

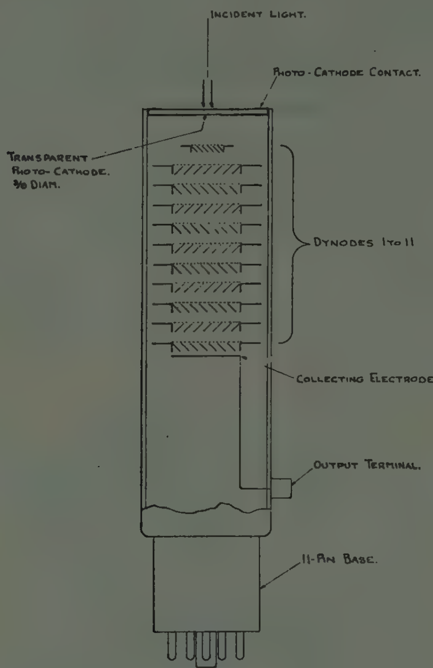


Fig. 9—Schematic arrangement of the electrodes in a Vx 5031 photomultiplier tube.

C. Grid-Controlled Multiplier Tubes

If one or more stages of electron multiplication are introduced between the control grid and the anode of a conventional thermionic amplifier tube, the effective grid to plate transconductance is multiplied by the gain of the multiplier unit. In addition, the static current through the multiplier unit will be increased by the same factor. The use of electron multiplication should result in an improvement of the figure of merit of a tube for the amplification of ultra-high-frequency signals since a high transconductance may be realized with a small, low capacity, grid structure. The application of electron multiplication to conventional grid-controlled amplifier tubes has been discussed by Thompson.[38]

The problems concerning the design of an electrode structure for the efficient use of electron multiplication have been investigated in various laboratories. Since most secondary electron surfaces are poisoned by material evaporated from the oxide coated cathode, it is necessary to place a shield between the cathode and the emitting surface. By means of suitable deflecting electrodes the beam of primary electrons is constrained to follow a curved path around the cathode shield.

Wagner and Ferris[39] have described an orbital beam electron multiplier suitable for wide band amplification at 500 megacycles. The grid plate transconductance was 15 ma/volt and the figure of merit $gm/\sqrt{C_1C_2}$ was nearly three times that of a 6AC7 tube operated with about the same plate current. In this expression for the figure of merit, gm is the transconductance and C_1 and C_2 are the effective input and output capacitances of the tube.

Fig. 10 illustrates the electrode structure of the E.M.I.-E1945 grid-controlled multiplier tube. This tube has been chosen as an example since the design is typical

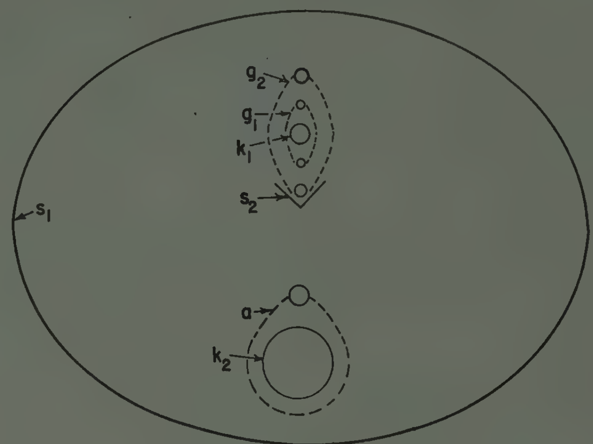


Fig. 10—Schematic arrangement of the electrodes in a typical (EMI-E1945) grid-controlled amplifier with one stage of electron multiplication.

for this type of tube and also because the tube has recently appeared on the market. The cathode K_1, control grid g_1 and screen grid g_2 perform the usual functions. The electron beam from the primary cathode system is focused by the elliptical electrode S_1 on to the secondary cathode K_2 which is surfaced with a complex coating of mixed oxides. The secondary electrons are collected by the grid anode a. The grid anode transconductance is 20 ma/volt when the tube is operated with an anode current of 25 ma. The figure of merit is approximately three times that of a 6AC7 tube.

IV. Particle Counting with Multiplier Tubes

A. Multiplier Tube Design

Electron multiplier tubes have been used with considerable success to count single electrons or positive ions. In this application the primary particles impinge upon the sensitive surface of the first electrode of the multiplier and eject one or more secondary electrons. The secondaries undergo further multiplication within the tube and the resulting pulses of current are recorded by conventional methods.

Bay[7] has described multiplier tubes with surfaces produced by heating magnesium in oxygen. The work function of this type of surface is sufficiently high to reduce the thermal emission of electrons to a negligible value. Single electrons, alpha particles, and X-ray photons were detected with these tubes.

The problems pertaining to the construction and operation of multiplier particle counters with oxidized beryllium surfaces have been discussed by Allen.[8] A

[38] B. J. Thompson, "Voltage-controlled electron multipliers," Proc. I.R.E., vol. 29, pp. 583–587; 1941.

[39] H. M. Wagner and W. R. Ferris, "The orbital-beam secondary-electron multiplier for ultra-high-frequency amplifications," Proc. I.R.E., vol. 29, pp. 598–602; November, 1941.

multiplier tube of improved design has also been described by Allen.[10] This tube is a 13-stage multiplier having electrodes of BeCu alloy. The average multiplication of the electrodes is similar to that represented by curve 2 of Fig. 3. A schematic diagram of the electrode assembly used in this tube is shown in Fig. 11. In

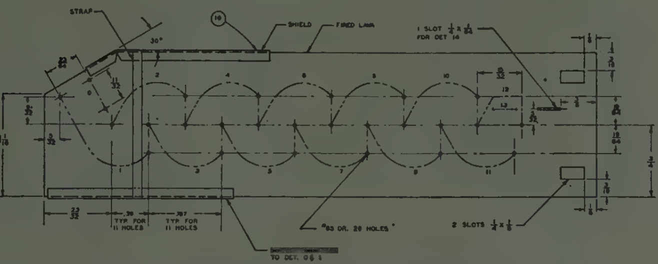


Fig. 11—Electrode structure of a 13-stage multiplier tube with BeCu alloy electrodes (after Allen[10]).

order to activate the electrodes, the entire electrode structure is placed inside a suitable glass tube. After evacuation of this tube, the electrodes are heated by radio-frequency induction at a temperature of about 600° C for 10 minutes. The assembly is then removed from the tube and mounted in the tube shell. The completed electrode system and metal tube shell are shown in Fig. 12. For additional information concerning the

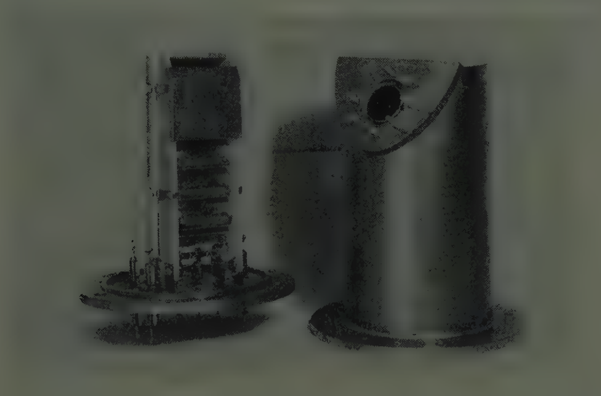


Fig. 12—The completed electrode system and metal tube shell for a 13-stage electron multiplier (after Allen[10]).

design of this type of tube the report by Dare and Rowen[40] is suggested as a reference.

Certain experiments require tubes with either a relatively large area photocathode or first multiplying electrode. The most efficient method for providing the large area surface is to introduce an electron lens between this surface and the usual multiplier structure. By means of this lens, the photoelectrons or secondary electrons are concentrated upon the first electrode of the multiplying unit.

Snell and Miller[41] have designed a tube with an electrode structure similar to that shown in Fig. 11, but with a first electrode of approximately three times the area of one of the succeeding electrodes. Particles entered the multiplier through a rectangular hole in an aperture plate which was separate from the multiplier proper and was bridged with a grid of fine wires. The application of an adjustable bias voltage between the grid and the first electrode, resulted in considerable discrimination between the pulses from alpha particles, 8 Kev protons and S^{35} betas.

Farago[42] has given a brief description of a tube with an enlarged photocathode of 100 cm² with an electron lens between this surface and the multiplier unit. A developmental tube C-7132 has been announced by RCA. This is a multiplier phototube with a transmission photosurface at one end of the tube. The area of this surface is 1.8 inches². As in the tubes mentioned above, the photoelectrons from the cathode are focussed into the multiplier structure.

B. Electron Counting

An electron multiplier with BeCu alloy surfaces has been used as an electron counter by Allen.[10] In this application, a well defined beam of mono-energetic electrons was allowed to strike the first electrode of the multiplier. In order to measure the absolute efficiency of the multiplier a relatively large current of primary electrons was measured by means of a Faraday cage and a direct-current amplifier. By means of a suitable slit system a known fraction of this current was allowed to enter the multiplier. The pulses from the multiplier were amplified by a conventional pulse amplifier and recorded by a scale of 4,096.

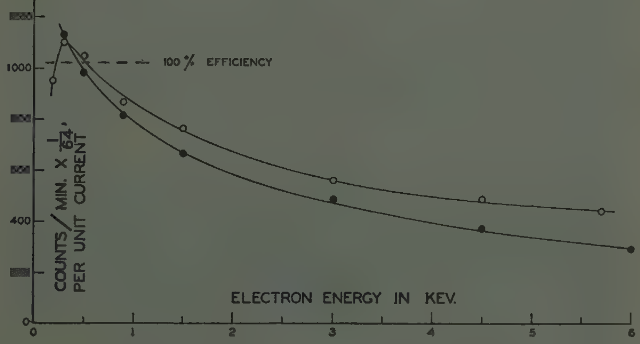


Fig. 13—The efficiency of a 13-stage multiplier tube as an electron counter. The gain of the pulse amplifier for the data of the upper curve was twice that used for the lower (after Allen[10]).

Fig. 13 shows the counting efficiency as a function of the energy of the primary electrons. The multiplier was operated with 375 volts per stage. The gain of the amplifier for the data of the upper curve was twice that used for the lower. The efficiency reached 100 per cent at 300 volts within the limits of accuracy imposed by the slit calibration. It can be seen that the efficiency was increased at the high energy end of the curve as the gain

[40] J. A. Dare and W. H. Rowen, Report No. 6, Lab. for Nuclear Science and Engineering, M.I.T.

[41] A. H. Snell and L. C. Miller, Private communication to the author.

[42] P. S. Farago, "Electron multiplier tube of large effective cathode surface area," *Nature*, vol. 161, p. 60; 1948.

of the amplifier was increased. This effect indicated that the relative number of low-energy secondary electrons per primary decreased as the energy of the primaries increased. As the amplifier gain was increased proportionably more of the smaller pulses were recorded for high-energy primaries.

Experiments with high-energy electrons have demonstrated that the counting efficiency is of the order of 5 to 10 per cent for 10^6 electron volts electrons. Eisenstein[43] has determined the electron counting efficiency of a tube having the 931-A electrode structure with beryllium coated surfaces. When a primary beam of 35 Kev electrons was allowed to fall on the cathode of this tube, the efficiency reached a value of 0.23 at 300 volts per stage of the multiplier. This value is in good agreement with that obtained from Fig. 5 using the dashed curve for aluminum. This curve represents the average number of low-energy secondaries ejected from an aluminum surface by a high-energy primary electron. The counting efficiency of a multiplier with a first electrode of a low Z element such as Be or Al is expected to show a similar variation with the energy of the primary beam. In order to increase the efficiency, the first electrode should be made of W or, perhaps, Pt rather than Be or BeCu.

C. Positive Ion Counting

The curves of Fig. 6 indicate that the SE yield for positive ions is considerably greater than unity for most metal surfaces. When the data of Healea and Hontermans[30] are combined with these curves, the complete SE yield curves are found to increase almost linearly with the energy of the positive ions in the region from 0 to about 4 Kev. The yield curves remain essentially constant for energies greater than 4 Kev. In view of these large values for the SE yield, the positive ion counting efficiency of an electron multiplier tube should be very nearly 100 per cent for energies greater than a few Kev.

The work of Allen[8] has shown that a 12-stage multiplier tube with Be coated electrodes is a reliable instrument for counting low energy H^+ ions. A more detailed study of the counting efficiency of a multiplier tube for positive ions has been made by Morrish and Allen.[44] The apparatus was identical with that used to obtain the electron efficiency data of Fig. 13. However, in this experiment a source of singly charged lithium ions was substituted for the electron source. The curves shown in Fig. 14 represent the counting rate as a function of the energy of the positive ions. The data for energies less than 4.5 Kev were obtained with the first electrode of the multiplier at ground potential and the data for higher energies were obtained with this electrode at -4.5 Kev. The data for each curve were recorded with a constant discriminator bias. A counting efficiency of 100 per cent corresponded to 375 counts per minute as recorded by the register of the scale of 256 counting circuit. The curves indicate that, for a sufficiently small discriminator bias, the counting efficiency approached 100 per cent for 2 Kev Li ions and probably remains at this value as the energy is increased.

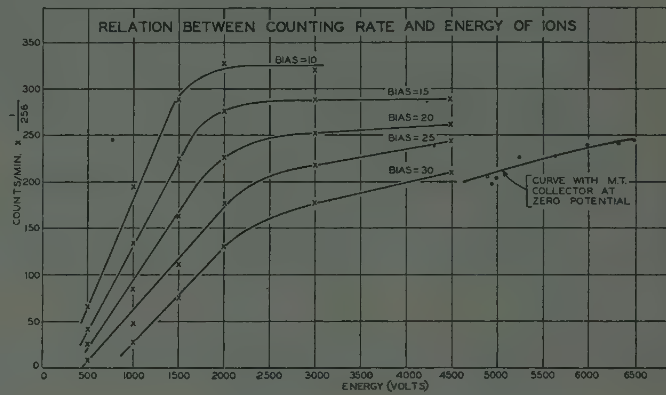


Fig. 14—The counting efficiency of a 13-stage multiplier tube for singly charged lithium ions. A rate of 375 counts per minute (scale of 256) corresponds to an efficiency of 100 per cent (after Morrish and Allen[44]).

Robson[45] has determined the absolute counting efficiency of a multiplier for low energy protons by a method similar to that described above. Fig. 15 has been reproduced from his paper and shows a series of bias curves for protons of various energies and also a bias curve for gamma rays. He concluded that the counting efficiency approached 100 per cent for protons of 5.75 Kev to 10 Kev energy. Absolute efficiency measurements were not made for protons with energies less than 5.75 Kev.

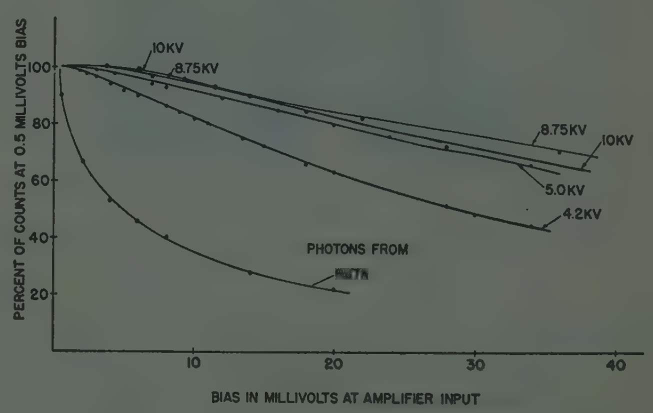


Fig. 15—Bias curves for an electron multiplier counting protons. The absolute counting efficiency approached 100 per cent for protons of 5.75 Kev to 10 Kev energy (after Robson[45]).

Experiments using alpha particle sources indicate that an alpha particle will eject, on the average, about 10 secondary electrons from a BeCu surface. The counting efficiency of a multiplier for alpha particles is very nearly 100 per cent, and should remain constant for a wide range of alpha particle energies.

[43] A. S. Eisenstein, O.N.R. Quarterly Report from the University of Missouri, December 15, 1948.

[44] A. H. Morrish and J. S. Allen, "Performance of the Allen type multiplier tube for lithium ion counting," *Phys. Rev.*, vol. 74, p. 1260; 1948.

[45] J. M. Robson, "Electron multiplier as a counter for 10-kev protons," *Rev. Sci. Inst.*, vol. 19, pp. 865–871; 1948.

D. Application of Multiplier Tubes to the Mass Spectrometer

Although the multiplier tube can be used as a sensitive positive ion detector, very few applications of this type of detector to the mass spectrometer have been reported. The most extensive studies of this application have been carried out by several students working under the direction of A. O. C. Nier of the department of physics, University of Minnesota. A preliminary report of an isotopic analysis of Rh, Cb and Ce has been published by Cohen,[46] and a more detailed report of this same investigation is to be found in his thesis.[47] In order to indicate some of the possibilities of a multiplier as applied to a mass spectrometer, a short summary of Cohen's work will be presented in this section.

A tube with multiplication at 11 stages was used by Cohen. The electrodes were of nonmagnetic, Nichrome V, and were coated with Be. The tube was operated with 265 volts per stage of multiplication. A schematic diagram of the tube at one end of a 60° Nier[48] type mass spectrometer is shown in Fig. 16. The collector of the

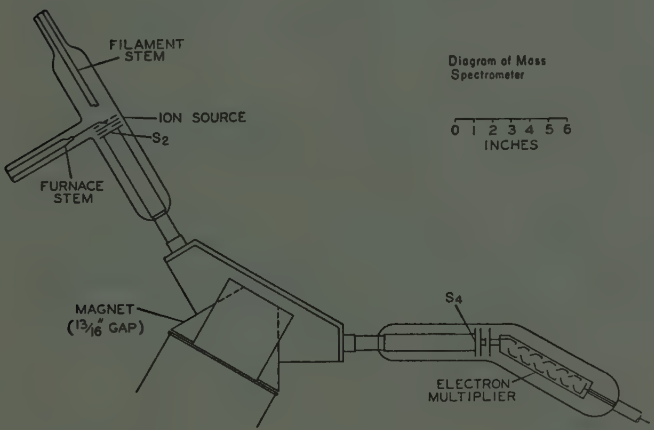


Fig. 16—Schematic diagram of an electron multiplier mounted on a Nier type mass spectrometer (after Cohen[46,47]).

multiplier tube could be connected either to an electrometer tube, dc amplifier, or to a pulse amplifier and scaling circuit. Fig. 17 shows the mass spectra of Ce obtained with this spectrometer. In this case, the output of the multiplier was connected to the dc amplifier. The current at the collector of the multiplier tube ranged from 10^{-9} to 10^{-8} amperes at the peak corresponding to mass 140. The fluctuations in this current were small, even at the lowest current levels.

In addition to the work mentioned above, Cohen has made a comparison of the signal to noise ratio expected when the positive ion current from the spectrometer is measured either by a dc amplifier or by a multiplier plus this same amplifier. Since this analysis is somewhat similar to that carried out by Zworykin, Morton and Malter,[1] and Shockley and Pierce,[49] the details will not be discussed here, but will be included in section V. As a result of his comparison, Cohen was able to show that the signal-to-noise ratio of the multiplier method is superior to that of the usual dc amplifier for ion currents less than 10^{-13} amperes.

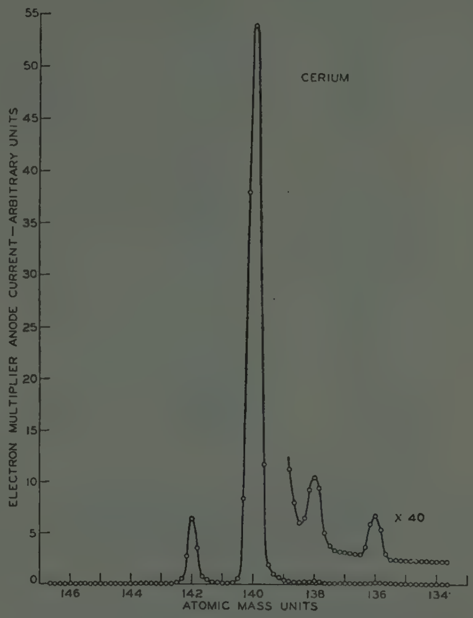


Fig. 17—The mass spectra of Cerium as obtained with the multiplier mass spectrometer shown in Fig. 16 (after Cohen[46,47]).

As an example of a more recent application of a multiplier to a mass spectrometer, a photograph of an electrode structure assembled on a flange is shown in Fig. 18. This flange may be mounted at the collector end of

Fig. 18—The electrode structure of a multiplier tube used on a mass spectrometer. The entrance slit for the ion beam is located between the two parallel plates at the top of the structure (after W. T. Leland, Dept. of Physics, University of Minnesota).

a Nier-type mass spectrometer. The electrodes are held in place by glass spacers, rather than by lavite strips as in some earlier models. The ion beam enters the electrode structure through the opening between the two parallel plates at the extreme top of the structure. In this installation the ion pulses are not counted, instead

[46] A. A. Cohen, "The isotopes of cerium and rhodium," *Phys. Rev.*, vol. 63, p. 219; 1943.
[47] A. A. Cohen, "The application of an electron multiplier mass spectrometer to the isotopic analysis of rhodium, columbium and cerium," Ph.D. thesis, Department of Physics, University of Minnesota.
[48] A. O. C. Nier, "A mass spectrometer to routine isotope abundance measurements," *Rev. Sci. Inst.*, vol. 11, pp. 212–216; 1940.
[49] W. Shockley and J. R. Pierce, "A theory of noise for electron multipliers," Proc. I.R.E., vol. 26, pp. 321–332; March, 1938.

the output current from the multiplier is amplified by a dc amplifier and the final output is read on a recording meter. Fig. 19 shows mass spectra obtained with this spectrometer when iodine is present. The mass 127 peak represents the single stable isotope of I and the peak at 128 is due to a small amount of HI present. No indication of an isotope at mass 129 is evident. Further spectra have shown that the relative abundance of this isotope, if it exists, is less than 3×10^{-7} that of I^{127}. The background fluctuations in the multiplier collector current are of the order of 10^{-17} amperes.

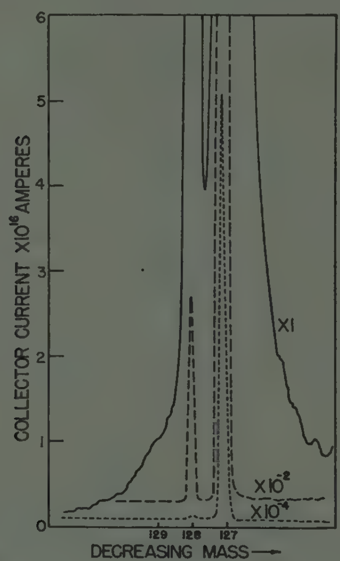


Fig. 19—The mass spectra in the region around mass 127 when iodine is present in the spectrometer. The 128 peak is due to a small amount of Hi present in the tube. The background fluctuations in the anode current of the multiplier are of the order of 10^{-17} amperes (after W. T. Leland).

The electron multiplier tube appears to have definite advantages over the usual methods of current measurement when the current is less than 10^{-13} amperes. In this current range the signal-to-noise ratio and stability of the multiplier are superior to that of a dc amplifier.

V. Statistical Fluctuations in Secondary Electron Emission

The problem of noise in electron multipliers is essentially that of evaluating the fluctuations in the output current in terms of the fluctuations in the input current and in the manner in which the secondaries are produced. This fluctuation noise may appear as relatively small fluctuations in a much larger current at the output of the tube, or as fluctuations in the pulse sizes recorded in a counting experiment. It will be convenient to consider separately these two types of noise, although they are actually identical.

A. Fluctuations in the Output Current of a Multiplier Tube

A theory of noise applicable to multistage electron multipliers has been developed by Shockley and Pierce[49] using methods similar to those employed by others for the analysis of the shot noise in the temperature limited current through a diode. In the case of multiplication at a single surface, the expression for the fluctuations in the current of secondary electrons becomes

$$\overline{\Delta I_s^2} = m^2\overline{\Delta I_p^2} + 2e\bar{I}_s mb\Delta f, \tag{1}$$

where

m = average number of secondaries per primary electron

δ^2 = mean-square deviation of this number

and $b=\delta^2/2$, the relative mean-square deviation. $\bar{I}_p$ and $\bar{I}_s$ are the average primary and secondary currents and $\Delta\bar{I}_p^2$ and $\Delta\bar{I}_s^2$, respectively, are the mean-square values of the fluctuations in $\bar{I}_p$ and $\bar{I}_s$. The amplitude of the noise is assumed to be constant within the frequency interval Δf. We may note that, except for the factor (mb), the second term is just the mean-square noise current to be expected for shot effect in the current $\bar{I}_s$. Thus the plate of a multiplier multiplies the input noise to it like a signal and adds to this a noise equal to (mb) times the shot noise corresponding to the output current.

An expression for the total noise in the output current of a multistage multiplier was obtained by Shockley and Pierce after applying (1) to each stage of the tube. If m and b are the same for all stages, the expression is

$$\overline{\Delta I_n^2} = M^2\Delta\bar{I}_p^2 + 2e\bar{I}_n[(M-1)/(m-1)]mb\Delta f, \tag{2}$$

where $\bar{I}_n$ is the average output current and M is the total multiplication of the n stages.

An expression identical to (2) was obtained by Zworykin, Morton, and Malter[1] with the assumption that the probability for the production of secondaries at each surface is given by Poisson's formula. Then $\delta^2=m$, $bm=1$, and the total noise current becomes

$$\overline{\Delta I_n^2} = 2e\bar{I}_n[(Mm-1)/(m-1)]\Delta f. \tag{3}$$

If there were no fluctuations in the multiplication process, $b=0$ and

$$\overline{\Delta I_n^2} = M^2\overline{\Delta I_p^2} = 2eM\bar{I}_n\Delta f. \tag{4}$$

A comparison of (3) and (4) shows that the fluctuations in the multiplicative process increase the noise current at the output of the multiplier by the factor $m/(m-1)$ when $Mm\gg1$. Since in practice $m=4$ to 5, the mean-square fluctuations in the output current are approximately 30 per cent greater than those expected if the primary current were multiplied by a noise-free amplifier of the same gain.

The results of various investigators have shown that, in general, the fluctuations in values of the multiplication at a surface do not follow a Poisson distribution. Ziegler[50] and Kurrelmeyer and Hayner[51] have made measurements of the average multiplication and the shot noise resulting from the fluctuations in this multiplication for a single secondary emitting surface. The curves of Fig. 20 represent the values of m and bm plotted

[50] M. Ziegler, "Shot effect of secondary emission," *Physica*, vol. 3, pp. 307–316; 1936.

[51] B. Kurrelmeyer and L. J. Hayner, "Shot effect of secondary emissions from nickel and beryllium," *Phys. Rev.*, vol. 52, pp. 952–958; 1937.

against E_p as obtained by these investigators for a surface of activated BaO and SrO and for a surface of oxidized Be. As mentioned earlier in this section, $\delta^2 = m$ and $bm = 1$ if the fluctuations in m follow a Poisson distribution. The values of bm are approximately equal to unity for $V_p = 100$ ev, but increase rapidly with increasing V_p. This indicates that the spread in the values of m is considerably greater than that predicted on the basis of a Poisson distribution.

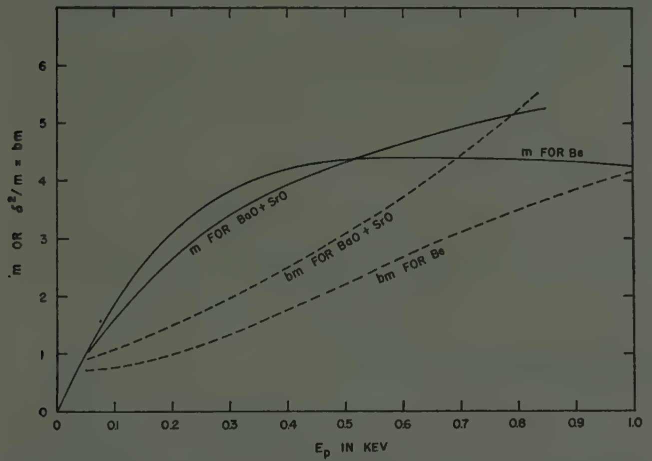


Fig. 20—m and δ^2/m for an oxidized Be surface and a surface of activated BaO plus SrO. If the fluctuations in m follow a Poisson distribution, then $\delta^2/m = 1$. The curves for the Be surface were reproduced from the work of Kurrelmeyer and Hayner[51] and those for the BaO-SrO surface are from the work of Ziegler.[50]

As an example, we may now complete the total mean-square noise expected when an n-stage tube with oxidized Be electrodes operated at 450 volts per stage is used to multiply a current of electrons or ions. Using $m = 4.3$ and $bm = 2.0$, (2) becomes

$$\overline{\Delta I_n^2} = 2eM\bar{I}_n\Delta f + 0.6(2eM\bar{I}_n)\Delta f, \tag{5}$$

or

$$\overline{\Delta I_n^2} = 2eM\bar{I}_n(1 + 0.6)\Delta f. \tag{6}$$

In this case, the mean-square current fluctuations are 60 per cent greater than those expected if the primary current were amplified by a noise-free current amplifier of gain M.

B. Pulse Size Fluctuations

When an electron multiplier tube is used with a pulse amplifier and scaling circuit to count single electrons or positive ions, a wide spread of pulse sizes is observed at the output of the multiplier. If identical particles are being counted, this distribution is due to the fluctuations in the value of the multiplication at each stage.

The statistics of the multiplicative process occurring in a multistage multiplier tube may be handled by the method of probability generating functions which was first used by Laplace.[52] The theory and several applications of this method have been reviewed by Frisch[53] and also by Jorgensen.[54] The basic equation for dealing with multiplicative processes was discovered by Ulam at the Los Alamos Laboratory and developed in a report by Hawkins and Ulam.[55] Since it is not the purpose of this report to develop the entire theory, only the results applicable to multiplier tubes will be given here.

We will consider an application in which a photomultiplier tube is used as a particle counter. A fluorescent material such as anthracene is placed near the photocathode and the absorption of a single particle in the anthracene will result in the ejection of photoelectrons from the cathode. Let the average number of photoelectrons per flash of light be m_0 and the mean-square deviation of this number be δ_0^2. In addition we will use the following definitions:

m_1 = average number of secondaries produced per primary at the first multiplying electrode
δ_1^2 = the mean-square deviation in m_1
m = average number of secondaries produced per primary at each of the succeeding $(n-1)$ stages of multiplication
δ^2 = the mean-square deviation in m
$M = m_1 m^{n-1}$, the over-all multiplication of the n stages of multiplication.

The expression for the relative mean-square deviation in the number of secondary electrons leaving the first multiplying electrode for each pulse of photoelectrons becomes

$$\Delta_1^2/m_0^2m_1^2 = \delta_0^2/m_0^2 + \delta_1^2/m_0m_1^2. \tag{7}$$

If single photoelectrons rather than groups leave the photocathode, $m_0 = 1$ and $\delta_0^2 = 0$ and (7) becomes $\Delta_1^2 = \delta_1^2$.

A relation similar to (7) may be applied to each of the stages in succession in order to obtain the relative mean-square deviation in the number of electrons per pulse at the output of the tube. The expression is

$$\Delta_n^2/m_0^2M^2 = \delta_0^2/m_0^2 + \delta_1^2/m_0m_1^2 + \delta^2/m_0m_1m^n\left[\frac{1 - m^{n-1}}{1 - m}\right]. \tag{8}$$

Since $m^{n-1} \gg 1$ for a multistage tube, (8) may be reduced to

$$\Delta_n^2/m_0^2M^2 = \delta_0^2/m_0^2 + \delta_1^2/m_0m_1^2 + \delta^2/m_0m_1m(m-1). \tag{9}$$

An equation of the same form as (9) has been derived by Shockley and Pierce[49] by essentially the same method as that employed here.

As an example, the relative mean-square deviation in the pulse sizes will be computed for an experiment in which single 450 ev electrons are being counted directly with a multiplier. The tube is assumed to have Be-

[52] "Oeuvers de Laplace," vol. 7, p. 1, Gauthier-Villars, 1886.
[53] O. R. Frisch, "The statistics of multiplicative processes," as yet unpublished.
[54] T. Jorgensen, Jr., "On probability generating functions," *Amer. Jour. of Phys.*, vol. 16, pp. 285–289; 1948.
[55] D. Hawkins and S. Ulam, "Theory of multiplicative processes I, LADC-265."

coated electrodes, and is operated with 450 volts per stage. In this case, $m_0=1$, $\delta_0=0$, $m_1=m=4.3$ and $\delta_1^2=\delta^2=8.6$. After substitution in (9),

$$\frac{\Delta_n^2}{M^2} = 0.47 + 0.14 = 0.61. \tag{10}$$

This example indicates that most of the noise originates in the first multiplication process, and that the distribution of pulse sizes at the output is exceedingly broad. Since the ratio δ^2/m^2 increases with m, the noise will also increase with m for this secondary emitting surface.

As a second example we may estimate the spread of the pulse size distribution when a photocathode is added to the tube described above. A crystal of anthracene is placed near the photo surface and this crystal is bombarded with beta-particles. If we assume that, on the average, 10 photoelectrons are recorded per pulse and that the fluctuations in this number follow a Poisson distribution, we have

$$\Delta_n^2/m_0^2M^2 = 0.1 + 0.06. \tag{11}$$

In this case the fluctuations due to the variation in the number of photoelectrons per pulse will be of the same order of magnitude as the fluctuations due to the multiplicative process. If the average number of photoelectrons per pulse is 100 rather than 10, the relative mean-square deviation in the output will be 0.016 corresponding to a rather narrow distribution of pulse sizes.

Radio Progress During 1949*

Introduction

As WE ENTER 1950, it is interesting to take a quick glance at the first half of the twentieth century, which witnessed a greater improvement in the standard of living throughout the civilized world than occurred in any equivalent period of time. While scientific and engineering developments tend to dominate our view of these advances, a certain intangible, but very real, factor must be recognized. This is the change in the attitude of the people and governments toward science, engineering, and industry. Particularly with regard to engineering, that attitude has changed from an initial incredulity at the turn of the century, on through an age of tolerant acceptance, to an enthusiastic demand for numerous products that have become household necessities even though of great technical complexity.

As might well be expected, this acceptance has been most complete among the younger members of our society. Their ready absorption of technical training, both in schools and through their immersion in the technical aspects of every-day life, contributes an invaluable running start to the next half century of progress.

In reviewing and assembling the items of progress for 1949 as reported by its special group of review experts, the committee was struck by the diversity of subjects about which radio engineers are thinking, as typified by the record of their reports and discussions. These differ quite a bit from the activities by which the radio industry presently derives the bulk of its income. Experience has shown that the problems of research and engineering of one period become the items of production five years later.

This multibillion dollar industry today is concerned with items that have become commonplace matters in most of its engineers' thinking at least. In most cases their present daily operations relate to the results of solutions of the problems that were discussed at meetings and in the technical press a few years ago.

From the viewpoint of the public, the most valuable contributions of the year were matters which received scant attention in the technical press: the many ingenious ways of improving the components or of simplifying circuits and systems whereby better but cheaper apparatus is offered for sale. During the year, hundreds of such expedients were utilized, the results of different methods of thinking in the engineering organizations of dozens of radio manufacturers, each spurred by an active competition for a higher placement in a growing market. These matters are rarely publicly reported and so do not get attention in scientific reports such as follows.

The example of television receiver design is typical—the more effective utilization of all materials in the set has given the public larger viewing screens, with fewer tubes and at cheaper prices—building up a former novelty into a national industry that is bringing about unusual changes in the country's spare time entertainment customs.

Along with this keen competition among manufacturers for marketable features in design the year has witnessed, finest co-operation is noted in the promotion of industry standards. Engineering time of inestimable value has been applied to IRE committee work. This has proved of great value to the industry at large.

* Decimal classification: R090.1. Original manuscript received by the Institute. January 30, 1950. This report is based on material from the 1949 Annual Review Committee of The Institute of Radio Engineers, as co-ordinated by the Chairman.

Activities in new fields have been undertaken by some committees, and a new IRE Committee has been set up to correlate and standardize methods in the field of measurements, a broad problem entering into all phases of the art.

Engineers have also co-operated in studying basic system possibilities that will help in formulating general communication standards by the national government agencies, and in establishing rules and recommended practices so that the best over-all results are assured.

Antennas and Waveguides

Antenna Theory

Books of interest to antenna engineers that appeared during 1949, included:

(1) S. Silver, "Microwave Antenna Theory and Design," Rad. Lab. Series, vol. 12, McGraw-Hill Book Co., New York, N. Y., 1949.
(2) "Tables of Generalized Sine- and Cosine-Integral Functions," Parts 1 and 2, Annals of the Computation Laboratory of Harvard University, Boston, Mass., 1949.

Electromagnetic horn radiators received considerable attention in the literature. The radiation patterns of horns having moderate flare angles were calculated from assumed field distributions over the aperture, using Schelkunoff's equivalence principle. An investigation showed that calculations of patterns using the Kirchhoff approximation to determine the far field can be surprisingly accurate. The impedance properties of sectoral horns were obtained using transmission line theory.

(3) C. W. Horton, "On the theory of the radiation patterns of electromagnetic horns of moderate flare angle," Proc. I.R.E., vol. 37, pp. 744–749; July, 1949.
(4) G. A. Woonton, D. R. Hay, and E. L. Vogan, "An experimental investigation of formulas for the prediction of horn radiator patterns," *Jour. Appl. Phys.*, vol. 20, pp. 71–78; January, 1949.
(5) H. S. Bennett, "Transmission-line characteristics of the sectoral horn," Proc. I.R.E., vol. 37, pp. 738–743; July, 1949.
(6) J. T. Bolljahn, "Some properties of radiation from rectangular-waveguides," Proc. I.R.E., vol. 37, pp. 617–621; June, 1949.

Super-gain antennas received further attention in a paper that discussed the dependence of gain on the phase distribution across the aperture of the antenna.

(7) D. A. Bell, "Gain of aerial systems," *Wireless Eng.*, vol. 26, pp. 306–312; September, 1949.

Further advances were made in the theory and application of lenses for controlling the radiation from antennas. A new type of artificial dielectric lens using baffle plates to effect a wave delay which produces a focusing effect, was described.

(8) S. B. Cohn, "Analysis of the metal-strip delay structure for microwave lenses," *Jour. Appl. Phys.*, vol. 20, pp. 257–262; March, 1949.
(9) S. S. D. Jones and J. Brown, "Metallic delay lenses," *Nature* (London), vol. 163, pp. 324–325; February 26, 1949.
(10) W. E. Kock, "Path-length microwave lenses," Proc. I.R.E., vol. 37, pp. 852–855; August, 1949.
(11) H. B. DeVore and H. Iams, "Microwave optics between parallel conducting planes," *RCA Rev.*, vol. 9, pp. 721–732; December, 1948.

The theory of radomes was extended by a theoretical and experimental investigation of the effects of dielectric sheets placed near antennas.

(12) R. M. Redheffer, "Microwave antennas and dielectric surfaces," *Jour. Appl. Phys.*, vol. 20, pp. 397–411; April, 1949.

An experimental and theoretical investigation of Yagi antennas produced methods for the approximate design of such antennas.

(13) R. M. Fishenden and E. R. Wiblin, "Design of Yagi aerials," *Jour. IEE*, (London), part 3, vol. 96, pp. 5–12; January, 1949.

The current distributions on infinitely long cylindrical antennas were calculated for excitations by a narrow axial slot and by a narrow transverse gap.

(14) C. H. Pappas and R. King, "Currents on the surface of an infinite cylinder excited by an axial slot," *Quart. Appl. Math.*, vol. 7, pp. 175–182; July, 1949.
(15) C. H. Pappas, "On the infinitely long cylindrical antenna," *Jour. Appl. Phys.*, vol. 20, pp. 437–440; May, 1949.

Further data on the helical antenna for producing circularly polarized waves were published. A general formula was shown for calculating the power received by an arbitrary antenna when receiving waves of arbitrary polarization.

(16) J. D. Kraus, "The helical antenna," Proc. I.R.E., vol. 37, pp. 263–272; March, 1949.
(17) Yung-Ching Yeh, "The received power of a receiving antenna and the criteria for its design," Proc. I.R.E., vol. 37, pp. 155–158; February, 1949.

A mathematical analysis of some experimental data on short antennas showed good agreement with theory. Also an investigation was made to determine the radiation resistances of antennas loaded with metal disks or dielectric sheaths to decrease the resonant frequency. Measurements of the mutual impedance between two parallel linear antennas showed fair agreement with theoretical values.

(18) L. C. Smeby, "Short antenna characteristics—theoretical," Proc. I.R.E., vol. 37, pp. 1185–1194; October, 1949.
(19) R. C. Raymond and W. Webb, "Radiation resistance of loaded antennas," *Jour. Appl. Phys.*, vol. 20, pp. 328–330; April, 1949.
(20) P. Starnecki and E. Fitch, "Mutual impedance of two centre-driven parallel aerials," *Wireless Eng.*, vol. 25, pp. 385–389; December, 1948.

Antenna Measurements

The effects of ground planes of finite dimensions on the measured impedances of vertical antennas mounted on them were shown to be quite appreciable. These measurements were made using a method described by Chipman that was shown to be closely related to the usual method of determining the standing-wave ratio directly.

(21) A. S. Meier and W. P. Summers, "Measured impedance of vertical antennas over finite ground planes," Proc. I.R.E., vol. 37, pp. 609–616; June, 1949.

Methods were described for determining the distribution of current and charge along an antenna, and some comparison of measured distributions were made with the theoretical distributions. A method was described for measuring the scattering of waves by antennas. A discussion of methods of measuring the gains of electromagnetic horns was presented.

(22) G. Barzilai, "Experimental determination of the distribution of current and charge along cylindrical antennas," Proc. I.R.E., vol. 37, pp. 825–829; July, 1949.
(23) W. Webb and R. C. Raymond, "Current distributions on some simple antennas," *Jour. Appl. Phys.*, vol. 20, pp. 330–333; April, 1949.
(24) D. D. King, "The measurement and interpretation of antenna scattering," Proc. I.R.E., vol. 37, pp. 770–777; July, 1949.

(25) A. S. Dunbar, and M. D. Adcock, "Measurement of the gain of electromagnetic horns," *Jour. Appl. Phys.*, vol. 20, pp. 226–227; February, 1949.

Slot Antennas

Theoretical and experimental data were published on the horizontal radiation patterns of axial slots in vertical cylinders with emphasis on methods of obtaining horizontally polarized nearly circular patterns.

Two articles dealt with radiation patterns of open ended waveguides, one a simple method of calculation by which a limited amount of information may be obtained, and in the other data were presented for a variety of shapes of the open end, and showing a shape which gave nearly uniform field over a wide angle. The fourth paper described the radiation patterns of circular slot antennas for mobile use.

(26) G. Sinclair, "The patterns of slotted-cylinder antennas," Proc. I.R.E., vol. 36, pp. 1487–1492; December, 1948.
(27) J. T. Bolljahn, "Some properties of radiation from rectangular waveguides," Proc. I.R.E., vol. 37, pp. 617–621; June, 1949.
(28) R. E. Beam, M. M. Astrahan, and H. F. Mathis, "Open-ended waveguide radiators," *Proc. NEC*, vol. 4, pp. 472–486; 1948.
(29) D. R. Rhodes, "Flush mounted antennas for mobile applications," *Electronics*, vol. 22, pp. 115–117; March, 1949.

Amplitude-Modulation Broadcast Antennas

The wide use of directive antennas has disclosed inadequate co-ordination of the characteristics of transmitter output circuits and those of the associated antennas. Two papers reported investigations pointing the way to improved performance in both fidelity of output signal and stability of operation.

(30) W. H. Doherty, "Operation of AM broadcast transmitters into sharply tuned antenna systems," Proc. I.R.E., vol. 37, pp. 729–734; July, 1949.
(31) J. C. Nonnekens, "Design considerations for directive antennas-arrays at medium-wave broadcast frequencies, taking into account the final radio-frequency amplifier circuits," *HF* (Brussels), pp. 26–31; 1949. (In English.)

Simplified methods were developed for calculating antenna radiation patterns for broadcast arrays.

(32) J. H. Battison, "Directional antennas for AM broadcasting," *Electronics*, vol. 22, pp. 101–103; April, 1949.

Frequency-Modulation Broadcast Antennas

A new design of "Cloverleaf" antenna, having power gains up to 12 and relatively free from the effects of icing, was described, as well as a "Multi-V" antenna having relatively broad-band characteristics.

(33) Phillip H. Smith, "A high gain cloverleaf antenna," *Proc. NEC.* (Chicago), vol. 4, pp. 497–504; published February, 1949.
(34) M. W. Scheldorf, "Multi-V antenna for FM broadcasting," *Electronics*, vol. 22, pp. 94–96; March, 1949.

Television Antennas

The requirements and mechanical construction of a loaded dipole suitable for indoor television reception were discussed. A reversible beam receiving antenna capable of covering 12 television channels was described.

(35) N. M. Best and P. J. Duffell, "Indoor television aerial," *Wireless World*, vol. 55, pp. 255–258; July, 1949.
(36) O. M. Woodward, Jr., "Reversible-beam antenna for twelve-channel television reception," *RCA Rev.*, vol. 10, pp. 224–240; June, 1949.
(37) "Built-in TV Aerial," *Tele-Tech*, vol. 8, pp. 37, 60; October, 1949.

Waveguides

During the year study was continued of the effect of various types of discontinuity in waveguides. The results obtained by loading the guide by disks or partitions were given further consideration.

(38) E. L. Chu, and W. W. Hansen, "Disk-loaded wave guides," *Jour. Appl. Phys.*, vol. 20, pp. 280–285; March, 1949.
(39) W. Walkinshaw, "Notes on wave guides for slow waves," *Jour. Appl. Phys.*, vol. 20, pp. 634–635; June, 1949.
(40) E. Kettel, "A waveguide with phase velocity $V<C$ for the E_{01} Wave," *Frequenz*, vol. 3, pp. 73–75; March, 1949.

The effect of slots in waveguide walls was treated rather simply, using transmission line theory with good agreement reported between theory and practice.

(41) A. L. Cullen, "Laterally displaced slot in rectangular waveguides," *Wireless Eng.*, vol. 26, pp. 3-10; January, 1949.
(42) G. Klages, "The effect of openings in the walls of metal waveguides on the wave propagation," *Arch. Elek.*, (Übertragung) vol. 3, pp. 85–92; March, 1949.

The propagation of TE_{01} waves in curved guides was considered, and the reflection from corners in rectangular waveguide was treated using conformal transformation.

(43) W. J. Albersheim, "Propagation of TE_{01} waves in curved wave guides," *Bell Sys. Tech. Jour.*, vol. 28, pp. 1–32; January, 1949.
(44) S. O. Rice, "Reflection from corners in rectangular wave guides—conformal transformation," *Bell Sys. Tech. Jour.*, vol. 28, pp. 104–135; January, 1949.
(45) S. O. Rice, "A set of second-order differential equations associated with reflections in rectangular wave guides—application to guide connected to horn," *Bell Sys. Tech. Jour.*, vol. 28, pp. 136–156; January, 1949.

The theory of microwave filters was extended and a parallel-resonator type of filter was described.

(46) S. B. Cohn, "Analysis of a wide-band waveguide filter," Proc. I.R.E., vol. 37, pp. 651–656; June, 1949.
(47) J. Hessel, G. Goubau, and L. R. Battersby, "Microwave filter theory and design," Proc. I.R.E., vol. 37, pp. 990–1000; September, 1949.
(48) J. R. Pierce, "Paralleled-resonator filters," Proc. I.R.E., vol. 37, pp. 152–155; February, 1949.

A method was indicated for reducing the reflection that occurs at a junction between uniform and tapered sections.

(49) L. Lewin, "Reflection cancellation in waveguides," *Wireless Eng.*, vol. 26, pp. 258–264; August, 1949.

The effect of surface roughness on eddy current losses was treated theoretically, and it was shown that scratches transverse to the direction of current flow may increase the power loss by as much as 100 per cent.

(50) Samuel P. Morgan, Jr., "Effect of surface roughness on eddy current losses at microwave frequencies," *Jour. Appl. Phys.*, vol. 20, pp. 352–362; April, 1949.

Transmission Lines

The characteristics of high-impedance coaxial cable having a helical inner conductor were calculated in two papers.

(51) S. Frankel, "High-impedance cable," Proc. I.R.E., vol. 37, p. 406; April, 1949.
(52) J. A. Hodelin, "Coaxial cable with high characteristic impedance," *Radio Franç.*, pp. 23–24; February, 1949.

The theory and method of construction of the "slab" transmission line were summarized.

(53) W. B. Wholey and W. N. Eldred, "A new type of slotted line section," *Proc. NEC*, vol. 4, p. 221; 1948.

A coaxial line bridge-type of network was described to deliver equal power to two inverse load impedances.

(54) R. W. Masters, "A power equalizing network for antennas," PROC. I.R.E., vol. 37, pp. 735–738; July, 1949.

Conditions in the terminal zone of a transmission line were investigated. It was shown that the effects of coupling between load and line may be allowed for by substitution of a terminal-zone network which must be evaluated for each type of termination.

(55) Ronold King and K. Tomiyasu, "Terminal impedance and generalized two-wireline theory," PROC. I.R.E., vol. 37, pp. 1134–1139; October, 1949.

Audio Techniques

During the year the Audio and Video Techniques Committee was replaced by three technical committees, the Audio Techniques, the Video Techniques, and the Sound Recording and Reproducing Committees.

The applications of audio design techniques to the solution of design problems involving both broadcasting studios and their associated equipment were reported. Another report covered the use of audio techniques in preventive medicine. Still another discussed the aural portion of television programs.

(56) W. W. Carruthers and D. P. Loye, "Building to the acoustical optimum. New Mutual-Don Lee Broadcasting Studios," *Jour. Acous. Soc. Amer.*, vol. 21, pp. 428–434, July, 1949.
(57) R. V. Kenney, "Studio control room design," *Audio Eng.*, vol. 33, pp. 21–23, 35–36; January, 1949.
(58) M. E. Gunn, "WMGM master control equipment design," *Audio Eng.*, vol. 33, pp. 24–28, 39–40; March, 1949.
(59) W. H. Offenhauser and M. C. Kahn, "The sounds of disease-carrying mosquitoes," *Jour. Acous. Soc. Amer.*, vol. 21, pp. 259–263; May, 1949.
(60) R. H. Tanner, "Audio Technique in television broadcasting," *Audio Eng.*, vol. 33, pp. 9–13, 41–44; March, 1949.

Excellent summary reviews appeared covering several aspects of the application of audio design techniques and the physical and physiological factors underlying audio-frequency engineering.

(61) H. A. Chinn, "Audio system design fundamentals," *Audio Eng.*, vol. 32, pp. 11–14, 41; November, 1948.
(62) W. K. Grimwood, "Volume compressors for sound recording," *Jour. Soc. Mot. Pic. Eng.*, vol. 52, pp. 49–76; January, 1949.
(63) L. S. Goodfriend, "Problems in audio engineering," *Audio Eng.*, vol. 33, pp. 22–23, 45, May, 1949; pp. 15–17, 34–35, June, 1949; pp. 20, 21, 37, July, 1949; pp. 19–20, 31, August, 1949; pp. 18–19, 46–47, September, 1949; pp. 23–25, October, 1949.
(64) S. J. Begun, "Magnetic Recording," Murray Hill Books, Inc., New York, N. Y.; 1949.
(65) J. G. Frayne and H. Wolfe, "Elements of Sound Recording," John Wiley and Sons, Inc., New York, N. Y.; 1949.

The factor of quality in the reproduction of sound received considerable coverage. Two reports covered listener reactions. The first discussed program material, associated acoustical and electronic equipment, size and nature of the audience, method used in reporting audience response, and statistical analysis of the audience response. The second discussed psychological factors, including listener fatigue and refers to the reported results of several other previous tests. A panel discussion on the general subject of high-quality reproduction took place in November, 1948, at a meeting of the Acoustical Society of America. The final item reported on quality improvement possibilities.

(66) L. S. Goodfriend, "Subjective testing of sound reproducing equipment," *Jour. Acous. Soc. Amer.*, vol. 21, pp. 81–84; March, 1949.
(67) C. J. LeBel, "Psycho-acoustic aspects of higher quality reproduction," *Audio Eng.*, vol. 33, pp. 9–11, 32–34; January, 1949.
(68) Summary review of panel discussion, "What constitutes high fidelity reproduction?," *Audio Eng.*, vol. 32, pp. 8, 36–38; December, 1948.
(69) D. Sarser and M. C. Sprinkle, "Mus'cian's amplifier," *Audio Eng.*, vol. 33, pp. 11–13, 53–55; November, 1949.
(70) J. M. Van Beuren, "Cost vs. Quality in a.f. Circuits," *FM and Telev.*, vol. 9, pp. 31–32, 34; February, 1949.

A trend toward size reduction was indicated in telephone repeaters, sound-level meters, and condenser-microphone assemblies.

(71) F. A. Minks, "The V3 Repeater," *Bell Lab. Rec.*, vol. 28, pp. 45–47; February, 1949.
(72) H. H. Scott, H. Chrystie, and E. G. Dyett, Jr., "Application of miniature circuit techniques to the sound level meter," *Proc. NEC*, vol. 4, pp. 33–45, 1948.
(73) J. K. Hilliard, "An omnidirectional microphone," *Audio Eng.*, vol. 33, pp. 20–21; April, 1949.

The continued attention to audio-frequency measurements is typified by several reports appearing during the year. One of these reviews, in correlated form, the theory involved in making measurements of gain, frequency response, distortion, and noise at audio frequencies, with particular emphasis on such measurements made on high-gain systems. Another, presented at the IRE National Convention in March, 1949, discussed the measurement of distortion with particular emphasis on comparisons among single-frequency harmonic measurement results and two intermodulation methods result. Another, an English report, reported measurement of audio-frequency noise. Two others reported the use of the cathode-ray oscilloscope and audio sweep frequency. Another report considered a method for the conversion of an audio signal to an output voltage which is proportional to sound level.

(74) W. L. Black and H. H. Scott, "Audio frequency measurements," PROC. I.R.E., vol. 37, pp. 1108–1115 (condensed); October, 1949. Also *Audio Eng.*, vol. 33, pp. 13–16, 38–43; October, 1949 and pp. 18–19, 48–50; November, 1949.
(75) A. P. G. Peterson, "The measurement of non-linear distortion," Engineering Department, General Radio Company, Technical Publication B-3; 1949.
(76) H. G. M. Spratt, "Noise and its measurement," *Elec. Rev.* (London), vol. 144, pp. 565–567; April 8, 1949.
(77) G. A. Argabrite, "Audio sweep frequency generator," *Audio Eng.*, vol. 33, pp. 11–13, 40–41; May, 1949.
(78) R. Toomin, "A new electronic audio sweep-frequency generator," *Audio Eng.*, vol. 33, pp. 23–26, 28–29; August, 1949.
(79) C. J. LeBel, "New developments in logarithmic amplifiers," *Audio Eng.*, vol. 33, pp. 15–17, 45–46; September, 1949.

Significant progress was made in standardization. "Definitions and Symbols for Audio Systems and Components," and "Methods of Measurement and Test for Audio Systems and Components," are the titles of two IRE subcommittees working in this field. In addition, the Engineering Department of the Radio Manufacturers Association brought to final stage a number of audio standards. In addition to those cited as actually published during the year, particular note should be taken of several others originated by the committee on Audio Facilities of the Transmitter Section of the RMA Engineering Department which were declared as RMA Standards: "Audio Facilities: Symbols and Designations for Single Line Diagrams," "Cable Connectors for Audio Facilities for Radio Broadcast-

ing," and "Standards for Audio Facilities for Radio Broadcasting Systems," the last of these being a revision and expansion of RMA Standard TR105A of the same title, published in May, 1948.

(80) RMA Standard, "Amplifiers for Sound Equipment," Engineering Department, *RMA*, SE-101-A; July, 1949.
(81) RMA Standard, "Panel Mounting Racks, Panels, and Associated Equipment," Engineering Department, *RMA*, SE-102; February, 1949.
(82) RMA Standard, "Speakers for Sound Equipment," Engineering Department, *RMA*, SE-103; April, 1949.
(83) RMA Standard, "Engineering Specifications for Amplifiers for Sound Equipment," Engineering Department, *RMA*, SE-104; May, 1949.
(84) RMA Standard, "Sound Systems," Engineering Department, *RMA*, SE-106; July, 1949.

Network and Circuit Theory

Linear Lumped-Constant Passive Circuits

The year was marked by the appearance of a book which presents a complete mathematical structure for the theory of circuit analysis, and the announcement of a surprising theorem. The theorem asserts that any driving-point impedance function has a physical representation which is free of transformers. It detracts but little from this astonishing and useful result that the representation may include a large number of superfluous elements.

(85) E. A. Guillemin, "The Mathematics of Circuit Analysis," John Wiley and Sons, New York, N. Y.; 1949.
(86) R. Bott and R. J. Duffin, "Impedance synthesis without use of transformers," *Jour. Appl. Phys.*, vol. 20, p. 816; August, 1949.

There has been continuing interest in the development of analogue devices to facilitate solution of the synthesis problem. These devices, of which the electrolytic tank is the prime example, make use of the analogue relating network functions to the two-dimensional electrostatic potential function.

(87) J. F. Klinkhamer, "Empirical determination of wave-filter transfer functions with specified properties," *Philips Res. Reports*, vol. 3, pp. 60–80; February, and pp. 378–400; October, 1948.
(88) A. R. Boothroyd, E. C. Cherry, and R. Makar, "An electrolytic tank for the measurement of steady-state response, transient response and allied properties of networks," *Proc. IEE*, part I, vol. 96, pp. 163–177; May, 1949.

Linear Varying—Parameter Circuits and Nonlinear Circuits

Several general reviews appeared summarizing past work and bringing the reader up to date concerning the types of problems which have been studied and the methods which are available for their solution.

(89) Mary L. Cartwright, "Nonlinear vibrations," *Advanc. Sci.*, vol. 6, pp. 64–75; April, 1949.
(90) A. A. Andronow and C. E. Chaikin, "Theory of Oscillations," English edition edited under direction of S. Lefschetz from 1937 Russian edition. Princeton University Press, Princeton, N. J., 358 p.
(91) W. R. Bennett, "A general review of linear varying parameter and nonlinear circuit analysis," presented, 1949 IRE National Convention, New York, N. Y., March 7, 1949.

Linear Active Networks

There was a noticeable consolidation of the theoretical progress of recent years. The versatility of feedback networks was emphasized in several novel applications. Of considerable interest was the increased use of combined positive and negative feedback. One such application employed controlled regeneration to compensate degenerative losses resulting from the elimination of bulky bypass capacitors.

(92) J. M. Miller, "Cathode neutralization of video amplifiers," Proc. I.R.E., vol. 37, pp. 1070–1073; September, 1949.
(93) P. G. Sulzer, "Circuit techniques for miniaturization," *Electronics*, vol. 22, pp. 98–99; August, 1949.
(94) A. B. Bereskin, "Cathode-compensated video amplification," *Electronics*, vol. 22, Part I, pp. 98–103; June, 1949. Part II, pp. 104–107; July, 1949.
(95) G. Newstead and D. L. H. Gibbings, "Error-actuated power filters," Proc. I.R.E., vol. 37, pp. 1115–1119; October, 1949.
(96) C. F. Brockelsby, "Negative-feedback amplifiers," *Wireless Eng.*, vol. 26, pp. 43–49; February, 1949.
(97) H. Mayr, "Feedback amplifier design," *Wireless Eng.*, vol. 26, pp. 297–305; September, 1949.
(98) F. D. Clapp, "Some aspects of cathode-follower design at radio frequencies," Proc. I.R.E., vol. 37, pp. 932–937; August, 1949.
(99) P. R. Aigrain, B. R. Teare, Jr., and E. M. Williams, "Generalized theory of the band-pass low-pass analogy," Proc. I.R.E., vol. 37, pp. 1152–1155; October, 1949.
(100) E. Labin, "Wideband television transmission systems," *Electronics*, vol. 22, pp. 86–89; May, 1949.
(101) P. A. T. Bevan, "Earthed-grid power amplifiers," *Wireless Eng.*, vol. 26, part I, pp. 182–192; June, 1949. Part II, pp. 235–242; July, 1949.
(102) A. Pinciroli and A. Taraboletti, "On the matrix analysis of linear networks comprising active four-terminal networks," *Alta Frequenza*, vol. 18, pp. 73–82, April, 1949.
(103) E. de Gruyter, "Resonance phenomena in oscillating circuits," *Assoc. Suisse Elect. Bull.*, vol. 39, pp. 791–801; November 27, 1948.

Time Domain Analysis and Synthesis

There appears to be a growing interest in the properties of signals and circuits expressed as functions of time rather than frequency. Despite the fact that much of our network theory and practice has grown around the sinusoidal function of time, the steady-state concepts of the frequency domain possess a certain artificiality when applied to communication systems that must transmit information. A sinusoidal signal is completely determined for all time from the outset whereas a signal that represents a message must contain unpredictable elements if it is to carry information. For this reason, the statistical properties of messages may best be formulated in the time domain, as may also various criteria of performance for the linear circuits and filters through which these messages must pass. Many of our familiar concepts in the frequency domain have their counterparts in the time domain (e.g., the correlation function versus the power-frequency spectrum, or the impulse response versus the gain and phase characteristics). The up-to-date communication engineer will find travel between the two domains necessary for a complete understanding of some problems. Two useful guides are:

(104) S. Goldman, "Transformation Calculus and Electric Transients," Prentice Hall, Inc., New York, N. Y.; 1949.
(105) C. Cherry, "Pulses and Transients in Communication Circuits," Chapman and Hall, Ltd., London.

The main benefit of working in the time domain is that one may formulate logical design criteria for optimizing the performance of the circuit under a given set of conditions. There is, for example, the matched-filter criterion for obtaining the greatest peak-signal

noise ratio from an input consisting of pulses of known shape corrupted by white noise. This criterion, which states that the impulse response of the filter should have the same shape as the input pulse except reversed in time, does not appear to be well known, even though it was stated several years ago in language of the frequency domain by Van Vleck and Middleton.

For optimum recovery and preservation of the waveform of a message that has been corrupted by noise, the "least-square" criterion is a reasonable basis for design. This criterion, which minimizes the average squared-difference between the desired response and that actually obtained, was used by N. Wiener in 1942 to develop a statistical theory of prediction and filtering. With the recent publication of his work, and the exposition, application, and extension of the theory by Y. W. Lee and others, the importance of the statistical point of view in communication engineering is emphasized.

(106) N. Wiener, "Extrapolation, Interpolation and Smoothing of Stationary Time Series," The Technology Press, MIT, and John Wiley and Sons, Inc., New York, N. Y.; 1949.
(107) Y. W. Lee, "Filtering and prediction," Lecture 5, AIEE-IRE Theory of Communication Series, New York, May 9, 1949.
(108) Y. W. Lee and C. A. Stutt, "Statistical prediction of noise," MIT Research Laboratory of Electronics Technical Report No. 129, July 12, 1949. Also, *Proc. NEC*, vol. 5; 1949.
(109) Y. W. Lee, T. P. Cheatham, and J. B. Wiesner, "The application of correlation functions in the detection of small signals in noise," MIT Research Lab. of Electronics Technical Report No. 141; October, 1949.

Unfortunately, the mathematical machinery available for use in the time domain is far more cumbersome and less satisfactory than that available in the frequency domain. Several related papers dealing with this difficulty were presented at the IRE National Convention last March. Summaries of these papers may be found in the PROCEEDINGS OF THE I.R.E. for February, 1949.

Several interesting methods for approximating a specified time response appeared during the year. These methods include a continued-fraction expansion of the Poisson-Stieltjes integral to obtain directly the driving-point impedance in the form of a ladder; expansion of the specified time response into a set of Laguerre functions and a network approximation thereunto in the sense of least-square error; and an interpretation of the transient response in terms of the critical frequencies of the system. The potential analogue was used to interpret the initial amplitudes of the transient oscillations in terms of the critical frequencies.

(110) M. Nadler, "The synthesis of electric networks according to prescribed transient conditions," PROC. I.R.E., vol. 37, pp. 627–630; June, 1949.
(111) P. R. Aigrain and E. M. Williams, "Design of optimum transient response amplifiers," PROC. I.R.E., vol. 37, pp. 873–879; August, 1949.
(112) J. H. Mulligan, Jr., "The effect of pole and zero locations on the transient response of linear dynamic systems," PROC. I.R.E., vol. 37, pp. 516–529; May, 1949.
(113) W. E. Thomson, "Transient response of wideband amplifiers," *Wireless Eng.*, vol. 26, pp. 264–266; August, 1949.
(114) R. C. Palmer and L. Mautner, "A new figure of merit for the transient response of video amplifiers," PROC. I.R.E., vol. 37, pp. 1073–1077; September, 1949.
(115) P. R. Aigrain and E. M. Williams, "Synthesis of *n*-reactance networks for desired transient response," *Jour. Appl. Phys.*, vol. 20, pp. 597–600; June, 1949.

To minimize the dispersion of pulsed signals, the time delay of the circuit should be constant over the frequency band of importance. This has been the subject of the following papers:

(116) M. H. Hebb, C. W. Horton, and F. B. Jones, "On the design of networks for constant time delay," *Jour. Appl. Phys.*, vol. 20, pp. 616–620; June, 1949.
(117) J. Laplume, "On the reduction of phase distortion in stages with coupled circuits," *Comp. Rend. Acad. Sci.* (Paris), vol. 227, pp. 1213–1215. See also pp. 187–188 and pp. 675–677; vol. 227, 1948.
(118) R. D. Kell and G. L. Fredendall, "Standardization of the transient response of television transmitters," *RCA Rev.*, vol. 10, pp. 17–34; March, 1949.

Circuit Components

A useful book, and one of the few written on the subject by the equipment designer rather than the manufacturer, is the "Components Handbook," which was released in 1949 as one of the MIT Radiation Laboratory Series.

The principle of the magnetic-fluid clutch has now been applied to several other applications. In one, a remote-controlled resistor is obtained by varying the magnetic field through a magnetic-fluid resistor consisting of an oil and ferrous-particle mixture, thus causing the suspended particles to reorient themselves and change the resistivity. In another, the material is used as a mold for small castings. This is done by placing the object to be cast in the fluid mixture, solidifying the mixture by means of a magnetic field, removing the pattern and pouring the casting, then liquifying the mold by removing the magnetic field.

The use of miniature tubes and components has become standard practice, and there is accelerated activity in subminiature development. Printed circuit techniques are also gaining ground.

(119) J. Markus, "Magnetic fluid uses," *Electronics*, vol. 22, pp. 120–122; September, 1949.
(120) W. G. Tuller, "Potted subassemblies for subminiature equipment," *Electronics*, vol. 22, pp. 104–105; September, 1949.
(121) M. A. Coler, "Properties of conductive plastics," *Electronics*, vol. 22, pp. 96–99; October, 1949.
(122) A. I. Dranetz, G. N. Howatt, and J. W. Crownover, "Barium titanates as circuit elements," *Tele-Tech*, vol. 8, in three parts, April, May, June, 1949.
(123) G. Shapiro and R. L. Henry, "Subminiaturization of i-f amplifiers," presented, 1949 IRE National Convention, New York, N. Y., March, 1949.
(124) J. F. Blackburn, ed., "Components Handbook," vol. 16 of MIT Rad. Lab. Series, McGraw-Hill, Book Co., New York, N. Y.; 1949.
(125) A. A. Pascucci, "New applications of a four-terminal titanate capacitor," presented, 1949 IRE National Convention, New York, N. Y., March, 1949.

Servomechanisms

Progress in the field of servomechanisms and closed-loop control systems has been in the direction of consolidation of theory, and in the refinement of techniques and computation aids. A number of analogue computers which can be used to solve control system equations have been developed. In addition, some work on the proper choice of error criterion to fit particular requirements has been done. Techniques for correlating transient with frequency response using simple methods have been developed. A notable factor is that the type of thinking developed in the field of servomechanisms has been applied to studies of many forms of active net-

works and even to the behavior of the human being as a control element. Considerable activity in the field of servomechanisms was apparent in foreign publications.

(126) G. S. Brown and D. P. Campbell, "Principles of Servomechanisms," John Wiley and Sons, Inc., New York, N. Y.,; 1948.
(127) A. B. MacNee, "An electronic differential analyser," Proc. I.R.E., vol. 37, pp. 1315–1324; November, 1949.
(128) G. D. McCann, C. H. Wilts, and B. N. Locanthi, "Electronic techniques applied to analogue methods of computation," Proc. I.R.E., vol. 37, pp. 954–961; August, 1949.
(129) H. Chestnut and R. W. Mayer, "Comparison of steady-state and transient performance of servomechanisms," *Trans. AIEE* vol. 68, T-9196; 1949.
(130) G. Newstead and D. L. H. Gibbings, "Error-actuated power filters," Proc. I.R.E., vol. 37, pp. 1115–1119; October, 1949.
(131) K. J. W. Craik, "Theory of human operator in control systems," *Brit. Jour. Psych.*, vol. 138, pp. 56–62; 1947, pp. 142–148; 1948.
(132) E. A. Mechler, J. B. Russell, and M. G. Preston, "The basis for the optimum aided-tracking constant," *Jour. Frank. Inst.*, vol. 248, pp. 327–334; October, 1949.
(133) E. G. Uderman, "A method of determining the parameters of linear automatic regulation systems," *Automat. i Telemakh.*, vol. 10, 1949 (in Russian).
(134) W. Z. Oppelt, "Locus methods for regulation processes with friction," *Zeit. Ver. dtsch. Ing.* (VDI), vol. 90; June, 1948.
(135) H. T. Marcy, M. Yachter, and J. Zauderer, "Instrument inaccuracies in feedback control systems with particular emphasis on backlash," *Trans. AIEE*, vol. 68, T-9197; 1949.

Electroacoustics

Acoustic Propagation and Impedance

Theory and experiment advanced together in the measurement and calculation of the acoustic impedance, both of acoustic elements such as ducts and orifices and of materials used as sound absorbers. Several simplified techniques for the measurement of the impedance of acoustic materials were developed. Theoretical refinements resulted in calculated absorption coefficients in fair agreement with measured values even for rather complex structures.

(136) C. T. Molloy, "The lined tube as an element of acoustic circuits," *Jour. Acous. Soc. Amer.*, vol. 21, pp. 413–418; July, 1949.
(137) R. H. Bolt, S. Labate, and U. Ingård, "The acoustic reactance of small circular orifices," *Jour. Acous. Soc. Amer.*, vol. 21, pp. 94–97; March, 1949.
(138) O. K. Marwardi, "Measurement of acoustic impedance," *Jour. Acous. Soc. Amer.*, vol. 21, pp. 84–91; March, 1949.
(139) R. W. Leonard, "Simplified acoustic impedance measurements," *Jour. Acous. Soc. Amer.*, vol. 21, p. 460; July, 1949 (abstract).
(140) R. K. Cook and Peter Chrzanowski, "Absorption by sound-absorbent spheres," *Jour. Acous. Soc. Amer.*, vol. 21, pp. 167–170; May, 1949.
(141) A. London, "Transmission of reverberant sound through double walls," *Jour. Acous. Soc. Amer.*, vol. 21, pp. 466; July, 1949 (abstract).
(142) L. L. Beranek and G. A. Work, "Sound transmission through multiple structures containing flexible blankets," *Jour. Acous. Soc. Amer.*, vol. 21, pp. 419–428; July, 1949.

An interesting group of experiments in the refraction of sound waves was performed. Acoustic lenses for airborne sound consisted of arrays of obstacles small compared to the wavelength. The small obstacles increased the effective density of the medium of propagation and so altered the refractive index. The principle is similar to that used in recently developed electromagnetic lenses for microwaves.

(143) W. E. Kock and F. K. Harvey, "Refracting sound waves," *Jour. Acous. Soc. Amer.*, vol. 21, pp. 471–481; September, 1949.

Pickup and Dispersion of Sound

The continuing desire of television and motion picture producers for smaller, less conspicuous microphones resulted in a light-weight directional microphone with improved response as compared to older models. Also, omnidirectional condenser microphones having dimensions well under one inch were developed. Concurrent with this development, subminiature circuit techniques were applied to preamplifiers for use with the tiny condenser microphones. In another approach to the problem of microphone placement for television sound pickup, three or more highly directional microphones were placed at fixed locations out of the camera line of sight. Action on the set was followed by fading from one microphone to another, this operation being performed at a monitoring console. The directional microphones, constructed especially for this application, were of a second order gradient type having uniform response and directivity between 50 and 15,000 cps. They could be used effectively at distances up to 12 feet with speech in conventional studios.

(144) H. F. Olson and J. Preston, "Single-element unidirectional microphone," *Jour. Soc. Mot. Eng.*, vol. 52, pp. 293–302; March, 1949.
(145) J. K. Hilliard, "An omnidirectional microphone," *Audio Eng.*, vol. 33, pp. 20–21; April, 1949.
(146) C. J. LeBel, "New developments in preamplifiers," *Audio Eng.*, vol. 33, pp. 9–12, 35; June, 1949.
(147) H. F. Olson and J. Preston, "Directional microphone," *RCA Rev.*, vol. 10, pp. 339–347; September, 1949.

Interest in wide-range reproducing systems for the home increased. A number of high-quality amplifiers were developed, some with triodes and others with beam tubes in the output stage, with and without feedback. Loudspeaker developments ranged from constructional details for residential installations to a new duo-cone speaker mechanism having relatively uniform response from 50 to 11,000 cps.

(148) J. D. Goodell and C. W. Fritze, "An unusual audio amplifier," *Radio Telev. News*, Radio-Electronic Edition, vol. 42, pp. 8–10, 31; March, 1949.
(149) D. T. N. Williamson, "High quality amplifier: new version," *Wireless World*, vol. 55, pp. 282–287; August, 1949.
(150) C. S. Mayeda, "A modern wide-range phono-amplifier," *Radio Telev. News*, Radio-Electronic Edition, vol. 42, pp. 46–48, 131–134; November, 1949.
(151) D. Sarsar and M. S. Sprinkle, "Musician's amplifier," *Audio Eng.*, vol. 33, pp. 11–13, 53–55; November, 1949.
(152) C. G. McProud, "New corner speaker design," *Audio Eng.*, vol. 33, pp. 14–17, 39; January, 1949.
(153) J. D. Goodell, "Loudspeaker enclosures," *Radio Telev. News*, Radio Electronic Edition, vol. 42, pp. 35–38, 118; November, 1949.
(154) M. Alixant, "Modern loudspeaker technique," *Radio Tech. Dig.* (France), vol. 3, pp. 83–99; April, 1949.
(155) C. T. Chapman, "Vented loudspeaker cabinets," *Wireless World*, vol. 55, pp. 398–400; October, 1949.
(156) H. F. Olson, J. Preston, and D. H. Cunningham, "New 15-inch duo-cone loudspeaker," *Audio Eng.*, vol. 33, pp. 20–23; October, 1949.

Speech and Hearing

Relatively few papers dealing with the intelligibility of speech under various listening conditions appeared during 1949. The visual portrayal of speech seems to have become routine and reports of progress deal largely with improvements in apparatus. No recent outstanding advances in hearing aid instrumentation or techniques were noted.

(157) I. Pollack, "The effect of white noise on the loudness of speech," *Jour. Acous. Soc. Amer.*, vol. 21, pp. 255–258; May, 1949.
(158) T. H. Schafer and R. S. Gales, "Auditory masking of multiple tones by random noise," *Jour. Acous. Soc. Amer.*, vol. 21, pp. 392–398; July, 1949.
(159) O. O. Gruenz and L. O. Schott, "Extraction and portrayal of pitch in speech sounds," *Jour. Acous. Soc. Amer.*, vol. 21, pp. 487–495; September, 1949.
(160) R. C. Mathes, A. C. Norwine, and K. H. Davis, "The cathode-ray sound spectroscope," *Jour. Acous. Soc. Amer.*, vol. 21, pp. 527–537; September, 1949.

Miscellaneous Transducers

A theory for piezoelectric crystal transducers based on the equation for the propagation of acoustic plane waves in solid media yields expressions for vibrational amplitude, radiated power, and electrical admittance, as well as the response for the entire frequency spectrum when the geometry and elastic parameters of the backing plate, crystal, diaphragm and surrounding medium are known. Transducer applications of the recently discovered ferroelectric ceramic, barium titanate, have received additional attention. A skillfully designed, direct-reading microdisplacement meter for use in measuring vibrational amplitudes of small objects, such as phonograph styli, was described. Amplitudes as small as 10^{-6} cm can be measured without imposing any load on the vibrating system. The theory of the reciprocity calibration of transducers was further unified and certain of the limits of the validity of reciprocity techniques have been established.

(161) W. G. Cady, "Crystal transducer theory," *Jour. Acous. Soc. Amer.*, vol. 21, pp. 65–73; March, 1949.
(162) H. W. Koren, "Application of activated ceramics to transducers," *Jour. Acous. Soc. Amer.*, vol. 21, pp. 198–201; May, 1949.
(163) J. P. Arndt, Jr., "Direct reading microdisplacement meter," *Jour. Acous. Soc. Amer.*, vol. 21, pp. 385–391; July, 1949.
(164) S. P. Thompson, "Theoretical aspects of the reciprocity calibration of electromechanical transducers," *Jour. Acous. Soc. Amer.*, vol. 21, pp. 538–542; September, 1949.
(165) W. Wathen-Dunn, "On the reciprocity free-field calibration of microphones," *Jour. Acous. Soc. Amer.*, vol. 21, pp. 542–546; September, 1949.

Electroacoustic Applications

Electroacoustic instrumentation and techniques at audio frequencies were found useful in the study of the physical properties of high polymer solids and solutions. Certain high polymer solutions which behave like liquids in steady flow were found to be able to support transverse waves at audio frequencies.

(166) J. D. Ferry, J. N. Ashworth, and W. M. Sawyer, "Rigidities of polyisobutylene and polyvinyl acetate solutions," *Phys. Rev.*, vol. 75, p. 1284; April 15, 1949 (abstract).
(167) R. S. Witte, B. A. Mrowca, and E. Guth, "Velocity and attenuation of sound in butyl and Gr-S rubbers," *Phys. Rev.*, vol. 75, p. 1284; April 15, 1939 (abstract).
(168) J. W. Ballou and J. C. Smith, "Acoustic measurements of polymer physical properties," *Phys. Rev.*, vol. 75, p. 1284; April 15, 1949 (abstract).

Ultrasonics

Additions in 1949 to literature in electroacoustics showed a rapid growth in the field of ultrasonics. Improved optical methods were devised for studying the propagation of ultrasonic beams in liquids. High concentrations of ultrasonic power in small regions were lenses. Interferometric techniques were developed for the accurate measurement of absorption coefficients of liquids at ultrasonic frequencies.

(169) R. B. Barnes and C. J. Burton, "Visual methods for studying ultrasonic phenomena," *Jour. Appl. Phys.*, vol. 20, pp. 286–294; March, 1949.
(170) G. W. Willard, "Focusing ultrasonic radiators." *Jour. Acous. Soc. Amer.*, vol. 21, pp. 360–375; July, 1949.
(171) F. E. Fox and Virginia Griffing, "Experimental investigation of ultrasonic intensity gain in water due to concave reflectors," *Jour. Acous. Soc. Amer.*, vol. 21, pp. 352–359; July, 1949.
(172) Daniele Sette, "Ultrasonic lenses of plastic materials," *Jour. Acous. Soc. Amer.*, vol. 21, pp. 375–381; July, 1949.
(173) F. E. Fox and J. L. Hunter, "The ultrasonic interferometer with resonant liquid column," Proc. I.R.E., vol. 36, pp. 1500–1503; December, 1948.

Ultrasonic techniques were found useful as tools of research in many fields of investigation. This was true in studies of the molecular structure and other properties of liquids. Shear elasticity of polymer liquids was demonstrated at ultrasonic frequencies. Depolymerization by ultrasonic irradiation was shown to be an effect of cavitation. Hydrolyzation was accelerated in certain instances by ultrasonic waves. The existence of alternating potentials accompanying the passage of ultrasonic waves through electrolytic solutions was established experimentally. The degree of dispersion of suspensions of clay by ultrasonic waves was shown to vary with frequency, passing through a maximum at a frequency characteristic of the type of clay.

(174) J. M. M. Pinkerton, "The absorption of ultrasonic waves in liquids and its relation to molecular constitution," *Proc. Phys. Soc. (London)*, vol. B62, pp. 129–141; February, 1949.
(175) E. Bauer, "A theory of ultrasonic absorption in unassociated liquids," *Proc. Phys. Soc. (London)*, vol. A62, pp. 141–154; March, 1949.
(176) W. P. Mason, W. O. Baker, H. J. McSkimin, and J. H. Heiss, "Measurement of the mechanical properties of polymer liquids by ultrasonic methods," *Phys. Rev.*, vol. 75, p. 1285; April 15, 1949 (abstract).
(177) A. Weissler, "Depolymerization by ultrasonic irradiation: The role of cavitation," *Phys. Rev.*, vol. 75, p. 1313; April 15, 1949 (abstract).
(178) Pierre Mastagli and Andre P. Mahoux, "Hydrolyzing effect of ultrasonic waves," *Compt. Rend. Acad. Sci.* (Paris), vol. 228, pp. 684–686; February 21, 1949.
(179) E. Yeager, J. Bughosh, F. Hovorka, and J. McCarthy, "The application of ultrasonic waves to the study of electrolytic solutions. II. The detection of the Debye effect," *Jour. Chem. Phys.*, vol. 17, pp. 411–415; April, 1949.
(180) Agnés Mathieu-Sicaud and Gustave Levavasseur, "Dispersion of suspensions of clay by ultrasonic waves. Interpretation of the results with the electron microscope," *Compt. Rend. Acad. Sci.* (Paris), vol. 228, pp. 393–395; January 31, 1949.

In gaseous media, the velocity of sound in superheated steam was measured by ultrasonic means, and the fringe displacement in an ultrasonic interferometer furnished a measure of the supersonic velocity of a stream of air.

(181) J. Woodburn, "Experimental determination of velocity of sound in superheated steam," *Trans. Amer. Soc. Mech. Engrs.*, vol. 71, pp. 65–70; January, 1949.
(182) Genevieve Dubois and Roger Kling, "Measuring the characteristics of a rapid current of gas by means of an ultrasonic beam," *Compt. Rend. Acad. Sci.* (Paris), vol. 228, pp. 363–364; January 31, 1949.

In the study of solids, ultrasonic techniques have yielded values of the mechanical parameters of Rochelle salt crystals. The elastic constants of both metals and plastics were measured. Ultrasonic methods circumvent the difficulties due to plastic flow in the case of thermo-

(183) W. J. Price, "Ultrasonic measurements on Rochelle salt crystals," *Phys. Rev.*, vol. 75, pp. 946–952; March 15, 1949.
(184) William C. Schneider and Charles J. Burton, "Determination of the elastic constants of solids by ultrasonic methods," *Jour. Appl. Phys.*, vol. 20, pp. 48–58; January, 1949.
(185) H. S. Sack and R. W. Aldrich, "Elastic losses of elastomers at ultrasonic frequencies," *Phys. Rev.*, vol. 75, p. 1285; April 15, 1949 (abstract).
(186) T. Hüter, "Propagation of ultrasonic waves in solid rods," *Zeits. Angew. Phys.*, vol. 1, pp. 274–289; January, 1949.

Research programs were initiated to investigate possible applications of ultrasonics in the fields of agriculture, biology, and medicine. The destructive effect of high-intensity ultrasonic fields on seeds and small plants was studied. Other agricultural interests were concerned with the influence of ultrasonic waves in insect and bacteria control, vitamin-C content, the occurrence of mutations in grains and plants, and others. In biology it was demonstrated that the disruption of cells, such as haemoglobin, in aqueous suspension in an ultrasonic field is due to the high acceleration of the cells rather than to cavitation. The use of ultrasonic irradiation as a therapeutic measure was the basis of several research projects. The absorption of ultrasonic waves in the 2–5 Mc region by animal tissue was found to increase as the first power of the frequency as contrasted with the frequency-squared relation for unassociated liquids. A new design of ultrasonic applicator was recently disclosed. It is intended for use in the treatment of various nerve and muscular disorders. The results of clinical tests were not yet reported.

(187) Jean Loza, "Effect of ultrasonic waves on the seeds and sprouts of higher plants," *Compt. Rend. Acad. Sci.* (Paris), vol. 228, pp. 595–596; February 14, 1949.
(188) L. E. Campbell and L. G. Schoenleber, "The use of ultrasonic energy in agriculture," *Agricult. Engng.*, vol. 30, pp. 239–241; May, 1949.
(189) O. A. Angerer, "On the question of the effective component of ultrasonic waves," *Naturwiss.*, vol. 36, No. 7, pp. 217–218; 1949.
(190) Th. Hüter, "Measurement of ultrasonic absorption in animal tissues," *Naturwiss.*, vol. 35, No. 9, pp. 285–286; 1948.
(191) F. Kopecik, "Ultrasonics in biology and medicine," *Ann. Telecommun.*, vol. 4, pp. 21221–21222; January, 1949.
(192) Amadeo Giacomini, "A contribution to the technique of research on the biological action of ultrasonic waves," *Nuovo Cim.*, vol. 6, pp. 39–49; January, 1949.
(193) Arthur Roberts, "Ultrasonic applicator," *Radio Telev. News*, Radio-Electronic Edition, vol. 12, pp. 3–5, 25; January, 1949.

Electron Tubes and Solid-State Devices

Small-Signal High-Vacuum Tubes

Traveling-Wave Tubes. Work on beam tubes employing continuous interaction, of which the beam traveling-wave tube may be considered as the prototype, was continued. It is shown that traveling-wave tubes will produce a gain even if the rf field at the mean position of the electron stream is purely transverse. The addition of a longitudinal magnetic focusing field reduces the gain due to transverse fields and increases the electron velocity for optimum gain.

(194) J. R. Pierce, "Transverse fields in traveling-wave tubes," *Bell Sys. Tech. Jour.*, vol. 27, pp. 732–746; October, 1948.

A new type of amplifier is described in which use is made of an electron flow consisting of two streams of electrons having different average velocities traveling in closely associated parallel paths. Experimental results are given showing 33-decibel gain at 255 megacycles with a 110-megacycle bandwidth. The power was less than one milliwatt.

(195) J. R. Pierce and W. B. Hebenstreit, "A new type of high-frequency amplifier," *Bell Sys. Tech. Jour.*, vol. 28, pp. 33–51; January, 1949.
(196) A. V. Haeff, "The electron-wave tube—a novel method of generation and amplification of microwave energy," Proc. I.R.E., vol. 37, pp. 4–10; January, 1949.
(197) A. V. Hollenberg, "The double-stream amplifier," *Bell Lab. Rec.*, vol. 27, pp. 290–292; August, 1949.
(198) L. S. Nergaard, "Analysis of a simple model of a two-beam growing-wave tube," *RCA Rev.*, vol. 9, pp. 585–601; December, 1948.
(199) P. Guenard, R. Berterottiere, and O. Doehler, "Amplification by direct electronic interaction in valves without circuits," *Ann. Radioélec.*, vol. 4, pp. 171–177; July, 1949.

A traveling-wave amplifier tube operating over the 6-to-8-centimeter band and designed for use as a repeater amplifier in a microwave communication link has been described. The tube operates at a beam voltage of 1,400, has a gain of 25 decibels, a power output of 140 milliwatts, efficiency of 2 per cent, bandwidth of 1,400 megacycles, and a noise factor of 18 to 20 decibels.

(200) D. C. Rogers, "Traveling-wave amplifier for 6 to 8 centimeters," *Elec. Commun.* (London), vol. 26, pp. 144–152; June, 1949.

A comparison of four slow wave propagating structures was made: the grid helix, the disk-loaded rod, apertured disk, and spiraled waveguide.

(201) L. M. Field, "Some slow wave structures for traveling-wave tubes," Proc. I.R.E., vol. 37, pp. 34–40; January, 1949.

Traveling-wave technique applied to an oscilloscope tube has resulted in a tube with flat frequency response from 0 to 500 megacycles for the recording of short recurrent high-frequency pulses.

(202) J. R. Pierce, "Traveling-wave oscilloscope," *Electronics*, vol. 22, No. 11, pp. 97–99; November, 1949.

A traveling-wave oscillator producing oscillations over a band of several octaves, the frequency being controlled by the dc voltage, was described.

(203) R. Schnitzer and D. Weber, *Frequenz*, vol. 3, pp. 189–196; July, 1949.

Several other papers concerned with theoretical studies of traveling-wave tubes appeared.

(204) O. Döhler and W. Kleen, "On the mode of operation of the traveling-wave valve," *Arch. elek. üebertragung*, vol. 3, pp. 54–63, 93–100; February and March, 1949.
(205) J. Laplume, "Theory of the traveling-wave valve," *L'Onde Elec.*, vol. 29, pp. 66–72, February, 1949.
(206) O. Doehler and W. Kleen, "On the efficiency of the traveling-wave valve," *Ann. Radioélec.*, vol. 4, pp. 216–222; July, 1949.
(207) L. N. Loshakov, "On the propagation of waves along a coaxial spiral line in the presence of an electron beam," *Jour. Tech. Phys.* (USSR), vol. 19, pp. 578–595; May, 1949.
(208) J. R. Pierce, "Circuits for traveling-wave tubes," Proc. I.R.E., vol. 37, pp. 510–515; May, 1949.
(209) J. R. Pierce and N. Wax, "A note on filter-type traveling-wave amplifiers," Proc. I.R.E., vol. 37, pp. 622–625; June, 1949.

New Tubes. A number of new tubes having interesting features were described, many of them being intended for operation at very-high frequencies. An oscillator tetrode, suitable for automatic frequency control in a

frequency-modulated set, was described in which a reflector electrode controls the transit time and hence the oscillation frequency.

(210) J. Kurshan, "The transitrol, an experimental automatic-frequency-control tube," *RCA Rev.*, vol. 9, pp. 687–703; December, 1948.

The design and possible application of a miniature secondary-emission type amplifier tube TR-1032-J was described. The second zero voltage characteristic of the dynode was utilized to obtain critically high conductance. Applications as a relaxation oscillator, multivibrator, pulse inverter, triangular wave generator and for dynatron service were suggested.

(211) C. F. Miller and W. S. McLean, "New design for a secondary emission trigger tube," Proc. I.R.E., vol. 37, pp. 952–954; August, 1949.

The application, design and limiting factors of electrometer tubes were discussed. Low grid current and high leakage resistance techniques were presented.

(212) J. A. Victoreen, "Electrometer tubes for the measurement of small currents," Proc. I.R.E., vol. 37, pp. 432–441; April, 1949.
(213) H. J. Starke, "A new subminiature electrometer tube," *Proc. NEC*, vol. 4, pp. 200–208; 1948.

An experimental beam-deflection tube for frequency modulation detection was described, which exhibits high sensitivity and amplitude to frequency modulation rejection but has small audio-frequency output.

(214) L. J. Giacoletto, "Experimental tube for FM detection," *Electronics*, vol. 22, pp. 87–89; November, 1949.

An experimental dual-control-grid pentode was described which used space-charge effects and grid alignments to give sharp cutoff characteristics for grids 1 and 3.

(215) R. F. Slinkman, "Design considerations for a dual control grid pentode," *Proc. NEC*, vol. 4, pp. 209–219; 1948.

Among a number of tubes for use at very-high frequencies was a new intermediate-frequency amplifier tube designed to operate with a bandwidth of 10 megacycles at a frequency of 15 megacycles. It has a transconductance of 12,500 micromhos and a gain-band product of 123.

(216) G. T. Ford, "The 404A, a broadband amplifier tube," *Bell. Lab. Rec.*, vol. 27, pp. 59–61; February, 1949.

A new microwave triode for radio relay amplifiers has a transconductance of 50,000 micromhos and gives a gain of 7–10 db with a 120- to 170-megacycle bandwidth at 4,000 Mc.

(217) J. A. Morton, "A microwave triode for radio relay," *Bell Lab. Rec.*, vol. 27, pp. 166–170; May, 1949.

A small planar triode for operation with a 10- to 15-megacycle bandwidth at 45 megacycles was described having a transconductance of 8,000 micromhos and input and output capacitances of 2.6 $\mu\mu$f and 1.1 $\mu\mu$f, respectively.

(218) "Planar electrode valves for vhf," *Wireless World*, vol. 45, pp. 165–167; May, 1949.

A new construction of disk-seal triode for ultra-high-frequency use has cylindrical elements arranged coaxially. Advantages of small size and of low heater wattage were obtained.

(219) G. M. Rose, D. W. Power, and W. A. Harris, "Pencil-type uhf triodes," *RCA Rev.*, vol. 10, pp. 321–338; September, 1949.

Two receiving triodes, an amplifier EC80 and an oscillator EC81 were described, the first featuring greatly reduced series resistance and inductance in the leads which make it useful as a grounded-grid amplifier to about 600 megacycles. The EC81 oscillator has an upper frequency limit of 1,500 Mc and will deliver 1.3 watts at 20 per cent efficiency at 750 megacycles. Both may be made on a production line and neither requires special circuits as with the disk-seal types.

(220) K. Rodenhuis, "Two triodes for reception of decimeter waves," *Philips Tech. Rev.*, vol. 11, pp. 79–89; September, 1949.

The beam-deflection principle has been applied to the design of mixer tubes for use at from 300 to 1,500 megacycles and for frequency-modulation detection.

(221) E. W. Herold and C. W. Mueller, "Beam-deflection mixer tubes for uhf," *Electronics*, vol. 22, pp. 76–80; May, 1949.

Electron-Tube Theory and Measurements. A number of papers contributing to the understanding of the general behavior of electron tubes appeared.

A universal set of diode characteristic curves based on the Epstein-Fry-Langmuir solution for the space-charge-limited current of a diode was published. These curves and the measured tube characteristics were used to estimate the series resistance of the cathode coating of some diodes.

(222) W. R. Ferris, "Some characteristics of diodes with oxide-coated cathodes," *RCA Rev.*, vol. 10, pp. 134–149; March, 1949.

A previously published solution of the electrostatic field in a parallel plane triode is discussed for cases where the spacing between grid wires is not small compared to the grid-cathode and grid-anode spacings.

(223) W. R. Bennett and L. C. Peterson, "The electrostatic field in vacuum tubes with arbitrarily spaced elements," *Bell Sys. Tech. Jour.*, vol. 28, pp. 303–314; April, 1949.

Space-charge free potential functions for a filamentary triode are obtained by the method of conformal transformation.

(224) E. C. Okress, "Potential functions for a thermionic vacuum tube," *Jour. Appl. Phys.*, vol. 20, pp. 850–855; September, 1949.

The input loading as a function of frequency was calculated for a diode drawing no direct current.

(225) N. A. Begovitch, "High-frequency total emission loading in diodes," *Jour. Appl. Phys.*, vol. 20, pp. 457–462; May, 1949.

A simplified method of determining the nonlinear characteristics of vacuum tubes was presented where the transconductance/grid voltage curve (especially its curvature at the operating point) determines performance as a modulator, frequency doubler, rectifier, etc.

(226) T. Slonczewski, "Transconductance as a criterion of electron tube performance," *Bell. Sys. Tech. Jour.*, vol. 28, pp. 315–328; April, 1949.

The variation of mutual conductance with frequency in a vacuum tube after 1,000 hours of life was found to be due to the deterioration of the contact between the oxide coating and the base material. This deterioration is evidenced by the increased capacitance and resistance

of the interface. This phenomena can be reduced by appropriate cathode shape. Cathode sparking and contact resistance were found to be related and the coating-to-core contact resistance must be less than 10 ohms per square centimeter to prevent sparking when emission current density is above 1 ampere per square centimeter.

(227) W. Raudorf, "Change of mutual conductance with frequency," *Wireless Eng.*, vol. 26, pp. 331–337; October, 1949.

The theory of the behavior of resistances at different frequencies is applied to resistive films existing between electrodes in vacuum tubes. It was shown that the capacitances of such films vary inversely as the square root of the frequency at high frequencies and approaches a limit at low frequencies. Experimental data given showed that the known frequency dependence of vacuum-tube interelectrode capacitances can be attributed to these resistive films.

(228) E. G. James and B. L. Humphreys, "Resistive films in valves," *Wireless Eng.*, vol. 26, pp. 93–95; March, 1949.

Measurements were made of the changes in grid-cathode and grid-anode capacitances of triode tubes as the operating conditions were changed. The influence of mutual conductance, amplification factor, and supply voltages were shown and a theory derived which is in fair agreement with experimental results.

(229) E. E. Zepler and J. Hekner, "Triode interelectrode capacitances," *Wireless Eng.*, vol. 26, pp. 53–58; February, 1949.

Results are given of measurements of the variation of interelectrode capacitance with change in operating conditions for several experimental electron tubes. Actual changes are considerably larger than those predicted by theory and indications are that the geometry and construction of the tubes play an important part in the magnitude of this change.

(230) B. L. Humphreys and E. G. James, "Interelectrode capacitance of valves," *Wireless Eng.*, vol. 26, pp. 26–30; January, 1949.

Formal expressions for properties of tubes in terms of integrals of the space currents were obtained which may eventually contribute to the solution of the multivelocity problem.

(231) J. K. Knipp, "On the velocity dependent characteristics of high frequency tubes," *Jour. Appl. Phys.*, vol. 20, pp. 425–431; May, 1949.

A paper on hum reduction has appeared on cathode-type tubes with particular regard to the influence of external and internal magnetic fields.

(232) A. F. Dickerson, "Hum reduction," *Electronics*, vol. 21, pp. 112–116; December, 1948.

Metallic elements of complex configuration and of high precision may be made by a new photogravure process.

(233) M. P. Wilder, "Electrodes for vacuum tubes by photogravure," Proc. I.R.E., vol. 37, pp. 1182–1184; October, 1949.

Noise. The noise spectrum of temperature-limited diodes was derived and the effects of transit time for both the cylindrical and planar case described. A curve showing the relation between transit angle and the necessary correction was given. The noise generated by electron movements can be easily determined by a new method described.

(234) D. B. Fraser, "Noise spectrum of temperature limited diodes," *Wireless Eng.*, vol. 26, pp. 129–131; April, 1949.

A general expression for the noise-power spectrum generated by the random emission of electrons of arbitrary trajectories within a waveguide was obtained. It was utilized to derive the equivalent mean-square fluctuation current due to the space charge within a diode for two cases of potential distribution, namely, linear distribution and that which occurs at the edge of the retarding field.

(235) J. J. Freeman, "Noise spectrum of a diode with a retarding field," *Jour. Res. Nat. Bur. Stand.*, vol. 42, pp. 75–88; January, 1949.

Emission. Significant new work on thermionic and secondary emission was reported. The use of a standard diode in evaluating emissive properties of a number of melts of base metal for oxide-coated cathodes was discussed. Methods of emission measurements were described that gave a reliable evaluation of melt lots resulting in a better control of the base metal.

(236) Robert L. McCormack, "A standard diode for electron-tube oxide-coated cathode-core-material approval tests," Proc. I.R.E., vol. 37, pp. 683–687; June, 1949.

The result of production tests on a number of cathode melt lots showed agreement (based on a figure of merit) among the receiving tube manufacturers on the poorest melt lot. However, agreement was not so conclusive regarding the best melt lot.

(237) J. T. Acker, "Testing cathode materials in factory production," Proc. I.R.E., vol. 37, pp. 688–690; June, 1949.

The free energy of some chemical reactions involving dissociation or reduction of alkaline earth oxides were computed.

(238) A. H. White, "Applications of thermodynamics to chemical problems involving the oxide cathode," *Jour. Appl. Phys.*, vol. 20, pp. 856–860; September, 1949.

The anode of output pentode DL41 coated with floccular soot was found to reduce the number of secondary electrons under conditions of low anode voltage. Increased power output with no increase in distortion results.

(239) J. L. H. Jonker, "Secondary emission in output valves," *Philips Tech. Rev.*, vol. 10, pp. 346–351; May, 1949.

Power-Output High-Vacuum Tubes

Triodes and Tetrodes. While not much attention has been paid to developing high power tubes for the lower frequencies in the past year, one paper describes an interesting method for surge testing such tubes. A 20-kilovolt, or higher, condenser discharge is used to reveal structural weakness and to study the effectiveness of a series resistor in the plate circuit to minimize destructive arcs during operation.

(240) H. J. Dailey, "Surge testing of high-voltage tubes," *Tele-Tech.*, vol. 8, pp. 26–29, 58–60; October, 1949.

The problem of obtaining more efficient cooling of power tubes was studied by several authors. In general,

more efficient heat transfer was obtained by increasing the turbulence of the cooling fluid.

(241) "Water-cooling vs. air-cooling for high-power valves," *Proc. IEE* (London), vol. 96, pp. 220–221; May, 1949.
(242) J. Prevost, J. Boissiere, and A. Loukobski, "Study and realization of a new system of forced-air-cooling for transmitting valves," *Ann. Radioélec.*, vol. 4, pp. 138–148; April, 1949.
(243) A. J. Young, "Radiators for transmitting valves," *Marconi Rev.*, vol. 12, pp. 85–91; July and September, 1949.
(244) M. J. Snijders, "A transmitting valve cooler with increased tubulence of the cooling water," *Philips Tech. Rev.*, vol. 10, pp. 239–246; February, 1949.

Continued interest in the development of power tubes for operation at frequencies above 100 megacycles is evident. Design considerations for a new series of glass power tubes having concentric cylindrical electrodes were discussed.

(245) E. G. Dorgelo, "Glass transmitting valves of high efficiency in the 100 mc/s range," *Philips Tech. Rev.*, vol. 10, pp. 273–281; March, 1949.

Other tubes for ultra-high frequencies, including one capable of producing 1.5 kilowatts at 300 megacycles, were reported.

(246) J. Bell and J. W. Davis, "The development of radio transmitting valves," *GEC Jour.*, vol. 16, pp. 138–149; July, 1949.

The problem of obtaining high power at high frequencies was attacked also by devising means for combining the outputs of several tubes. One method employs a bridge-type circuit which eliminates interaction of tubes. This approach may have considerable influence on power tube development.

(247) D. L. Balthis, "A coaxial 50 kw FM broadcast amplifier," *Electronics*, vol. 22, pp. 68–73; May, 1949.
(248) R. R. Law, W. B. Whalley, and R. P. Stone, "Developmental television transmitter for 500–900 megacycles," *RCA Rev.*, vol. 9, pp. 643–652; December, 1948.
(249) G. H. Brown, W. C. Morrison, W. L. Behrend, and J. G. Reddeck, "Method of multiple operation of transmitter tubes particularly adapted for television transmission in the ultra-high-frequency band," *RCA Rev.*, vol. 10, pp. 161–172; June, 1949.

General Theory and Design. Several studies of a theoretical nature were made in regard to tube structure and operation.

(250) G. R. Partridge, "Factors influencing the perveance of power-output triodes," PROC. I.R.E., vol. 37, pp. 87–94; January, 1949.
(251) T. Slonczewski, "Transconductance as a criterion of electron tube performance," *Bell Sys. Tech. Jour.*, vol. 28, pp. 315–328; April, 1949.
(252) W. R. Bennett and L. C. Peterson, "The electrostatic field in vacuum tubes with arbitrarily spaced elements," *Bell Sys. Tech. Jour.*, vol. 28, pp. 303–314; April, 1949.
(253) R. R. Law, "Electronics of ultra-high-frequency triodes," PROC. I.R.E., vol. 37, pp. 273–274; March, 1949.

Other papers touched on many practical aspects of tube design.

(254) J. Becquemont, "Series of modern tubes for frequency modulation and television," *L'Onde Elec.*, vol. 28, pp. 145–152; April, 1949.
(255) R. Remillon, "Modern methods for measurement of characteristics and limitations of electron tubes at uhf and vhf." *L'Onde Elec.*, vol. 29, pp. 273–285; 330–346; July and August, 1949.
(256) B. Aumont, "Problems of manufacture of tubes for very-high frequencies," *L'Onde Elec.*, vol. 29, pp. 271–273; July, 1949.
(257) H. D. Doolittle, "Design problems in triodes and tetrodes for hf," *Communications*, vol. 29, pp. 14–17; June, 1949.

New Developments. In a new device, suitable for the amplitude modulation of magnetrons or other generators of radio-frequency power not otherwise easily modulated, a beam of electrons is passed through a resonant cavity where the radio-frequency energy, along with a fixed magnetic field, causes the beam to spiral as it absorbs power from the circuit. The amount of energy absorbed may be controlled by varying the voltage or current of the beam.

(258) J. S. Donal, Jr., and R. R. Bush, "A spiral beam method for amplitude modulation of magnetrons," PROC, I.R.E., vol. 37, pp. 375–382; April, 1949.

A further extension of the above device has also an output cavity where the energy of the spiral beam may be extracted and fed to a load. This results in a much more efficient modulator.

(259) C. L. Cuccia, "The electron coupler—a developmental tube for amplitude modulation and power control at ultra-high frequencies," *RCA Rev.*, vol. 10, pp. 270–303; June, 1949.

Gas Tubes

The ability of the tube to deionize during the nonconducting portion of the cycle depends on a number of factors, such as grid voltage, grid resistance, and mercury temperature. New methods of measuring deionization time using pulse methods of application of tube voltages have been presented.

(260) H. A. Rowanowitz, "Measurements, Analysis, and Statistical Nature of Deionization Time in a Mercury Thyratron," University of Kentucky, College of Engineering, Lexington, Kentucky.
(261) H. de B. Knight, "Deionization time of thyratrons—a new method of measurement," *Proc. IEE* (London), vol. 96, part 3; July, 1949.

A detailed study was made on the effect of gas pressures and other design features which have an important bearing on the usefulness of thyratrons in high-pulse-rate modulators.

(262) H. H. Wittenberg, "Thyratrons in radar modulator service," *RCA Rev.*, vol. 10, p. 116; March, 1949.

Phototubes

A wide variety of photoconductive materials were studied. Lead sulfide cells appear to advantage over conventional phototubes as pickup devices for motion picture sound; the sensitivity is high, the noise low, response to low color temperature good, and the frequency response adequate. Lead telluride and lead selenide which have infrared responses to 5.5 and 4.5 μ are better than the lead sulfide cells only for the infrared beyond the PbS threshold (3.5 μ) or when they are cooled to improve the signal-to-noise ratio. Excess metal and oxygen activation appear necessary in most photoconductors reported. Of the many metallic sulfides, selenides, and tellurides, those of the following may be listed: Pb, Sn, In, Tl, Cd, Bi, Sb. Many are characterized by poor frequency response.

(263) S. Pakswer, "Lead sulfide photoconductive cells," *Electronics*, vol. 22, p. 111; May, 1949.
(264) E. Schwarz, "New photoconductive cells," *Nature* (London), vol. 162, pp. 614–615; October 16, 1948.
(265) C. J. Milner and B. N. Watts, "Lead selenide photoconductive cells," *Nature*, (London) vol. 163, p. 322; February 26, 1949.
(266) P. Gorlich and J. Heyne, "On a new photoconductive cell for the visible," *Optik*, vol. 4, pp. 206–212; November and December, 1948.

Geiger-Müller Counter Tubes. The optimum proportions for Geiger-Müller tubes of small size, the effects of various hydrocarbon mixtures on the starting voltage, the effects of the tube proportions and filling gas on the plateau shapes, and the occurrence of spurious discharges were described. The poor performance of methylene bromide as a quenching agent was attributed to electron attachment.

(267) C. V. Robinson and R. E. Peterson, "Study of small ether-argon Geiger-Mueller counters," *Rev. Sci. Instr.*, vol. 19, pp. 911–914; December, 1948.
(268) P. B. Weisz "Starting potential of the Geiger-Mueller counter discharge," *Phys. Rev.*, vol. 74, pp. 1807–1812; December 15, 1948.
(269) A. G. Fenton and E. W. Fuller, "Further experiments with an adjustable Geiger-Mueller counter," *Proc. Phys. Soc.* (London) vol. 62A, pp. 32–40; January, 1949.
(270) J. H. Carver and G. K. White "Methylene bromide as a quenching agent in Geiger-Mueller counters," *Nature* (London) vol. 163, pp. 526–527; April 2, 1949.

Construction details of counter tubes for special purposes were also described.

(271) J. R. Beyster, et al., "Cell-type gamma counter," *Rev. Sci. Instr.*, vol. 19, pp. 819–820; November, 1948.
(272) M. Lesage, et al., "Sur la construction des compteurs Geiger-Müller in type metallique, *Jour. Phys. Radium*, Series 8, vol. 10, pp. 212–214; June, 1949.
(273) E. J. Harris, "A Geiger tube for liquid radioactivity measurements," *Jour. Sci. Instr. and Phys. in Ind.*, vol. 26, p. 245; July, 1949.
(274) F. E. Senftle et al., "Construction of beta-Geiger counters from prefabricated thin wall tubing," *Rev. Sci. Instr.*, vol. 20, pp. 370–371; May, 1949.

Success was reported in rejuvenating defunct counter tubes by glowing the anode wire in a vacuum before refilling. The temperature dependence of self-quenching counters may be attributed to the condensation of liquid films on the inside of the tube forming leakage paths. Spurious counting rate was attributed to the emission of an ionizing agent from freshly polished or warmed metals.

(275) L. Shepard, "Rejuvenation of Geiger-Mueller tubes," *Rev. Sci. Instr.*, vol. 20, pp. 217–218; March, 1949.
(276) O. Parkash, "On temperature dependence of counter characteristics in self-quenching G-M counters," *Phys. Rev.*, vol. 76, pp. 568–569; August, 15, 1949.
(277) J. D. Louw and S. M. Naude, "Spurious counts in Geiger counters and the pretreatment of the electrodes," *Phys. Rev.*, vol. 76, pp. 571–572; August, 15, 1949.

A marked reduction in the background rate of a gamma counter can be achieved by surrounding it with auxiliary counters in anticoincidence inside the customary lead shield. A quench circuit with a "self-quenching" counter tube was investigated.

(278) J. L. Putman, "A study of background rate in Geiger-Müller counters and the pretreatment of the electrodes," *Jour. Sci. Instr. and Phys. in Ind.*, vol. 26, pp. 198–201; June, 1949.
(279) H. Elliot, "The effect of external quenching on the life of argon-alcohol counters," *Proc. Phys. Soc.*, vol. 62A, pp. 369–373; June, 1949.

An article described various types of counter tube construction and summarized a great deal of information on filling gases. Another article reviewed the factors such as time lag, quenching, and dead time, which affect the speed of operation of counters.

(280) H. Friedman, "Geiger counter tubes," Proc. I.R.E., vol. 37, pp. 791–808; July, 1949.
(281) H. den Hartog, "Speed of operation of Geiger-Müller counters," *Nucleonics*, vol. 5, pp. 33–47; September, 1949.

Cathode-Ray Tubes and Television Tubes

The trend toward larger television pictures was accelerated by introduction of a new 16-inch metal kinescope. The metal construction greatly facilitated the production of large direct-view tubes. Late in the year, a 19-inch metal kinescope was also introduced. Increased interest and development of theater projection tubes has continued.

(282) H. P. Steier, J. Kelar, C. T. Lattimer, and R. D. Faulkner, "Development of a large metal kinescope for television," *RCA Rev.*, vol. 10, pp. 43–58; March, 1949.

In the camera tube field, a new tube was described, called the image isocon, which is similar to the image orthicon but generates a video signal of opposite polarity, with maximum signal in the light, resulting in improved signal-to-noise ratio in the dark parts of the picture. The image isocon is more complicated to make, more critical to adjust, and has a resolution and time lag somewhat inferior to those of the image orthicon.

A detailed account of the development, construction, and operation of several types of image orthicon camera tubes was published. A description was given of the new type image orthicon having improved spectral response, higher sensitivity, and greater range in flexibility in television pickup, outside or in the studio.

(283) P. K. Weimer, "The image isocon—an experimental television pickup tube based on the scattering of low velocity electrons," *RCA Rev.*, vol. 10, pp. 366–386; September, 1949.
(284) R. B. Janes, R. E. Johnson, and R. S. Moore, "Development and performance of television camera tubes," *RCA Rev.*, vol. 10, pp. 191–223; June, 1949.
(285) R. B. Janes, R. E. Johnson, and R. R. Handel, "A new image orthicon," *RCA Rev.*, vol. 10, pp. 586–592; December, 1949.

A new type of picture storage tube, the graphecon, has two electron guns which can operate simultaneously to write and read information from an insulated target. The target is a thin film insulator which in addition to having long-time storage capability has the important feature that electron bombardment-induced conduction provides high sensitivity and stability.

The problems of negative-ion blemish in cathode-ray tubes were discussed and various methods of eliminating ion blemish were summarized. An interesting summary of several methods of preparation of luminescent screens for cathode-ray tubes was given, along with a discussion of the problems of making and the performance characteristics of screens applied by the different methods.

(286) L. Pensak, "The graphecon—A picture storage tube," *RCA Rev.*, vol. 10, pp. 59–73; March, 1949.
(287) R. M. Bowie, "The negative-ion blemish in a cathode-ray tube and its elimination," Proc. I.R.E., vol. 36, pp. 1482–1486; December, 1948.
(288) M. Sadowsky, "The preparation of luminescent screens," *Jour. Electro Chem. Soc.*, vol. 95, pp. 112–128; March, 1949.

A secondary-emission trigger tube having a long-life secondary-emission dynode surface and provided with two output electrodes for rapid switching and signal generator applications was described.

An important contribution in the field of electron optics is the theory and design of electron beams treated in a recent book by J. R. Pierce.

The measured properties of strong unipotential lenses of various types were reported. These measurements re-

sulted in the design of a unipotential lens from which the diverging parts of the electrostatic field are removed, giving a lens with as low spherical aberration as a magnetic lens of comparable size.

A calculation was made of the potential distribution, maximum current density and beam spread for tubular electron beams which shows that such beams have advantages in greater maximum current density and less spreading—at least for current densities less than the maximum.

A particular aberration phenomena in electrostatic electron lenses was reported, where a dark kidney-shaped object in a bright field appears when one of two limiting apertures is in a cross-over region of the electron beam.

(289) C. F. Miller and W. S. McLean, "New design for a secondary-emission trigger tube," Proc. I.R.E., vol. 37, pp. 952–954; August, 1949.
(290) J. R. Pierce, "Theory and Design of Electron Beams," D. Van Nostrand Co., Inc., New York, N. Y.; 1949.
(291) G. Liebmann, "Measured properties of strong unipotential electron lenses," *Proc. Phys. Soc.* (London), vol. 62, pp. 213–228; April, 1949.
(292) N. Wax, "Some properties of tubular electron beams," *Jour. Appl. Phys.*, vol. 20, pp. 242–247; March, 1949.
(293) S. Harrison, "Aberration phenomeonon in electrostatic lenses," *Jour. Appl. Phys.*, vol. 20, pp. 412–413; April, 1949.

The general theory of magnetic focusing in a plane was applied to the asymmetric case and the possibility of a reduction of aberrations was found. These results were shown to be special cases of a further general second-order focusing condition. Calculations of the theoretical limit of resolution of the electron microscope show that the condition for spherical correction is in contradiction to the principles of good design.

In electron microscopes it was shown that the contrast of thin films can be increased by introduction of a phase delay and defocusing. An experimental simple magnetic beam-splitting device of interest to operators of electron microscopes was also described.

(294) L. Kerwin and C. Geofferton, "Further improvements in magnetic focusing," *Rev. Sci. Instr.*, vol. 20, pp. 381–384; June, 1949.
(295) H. Hintenberger, "Improved magnetic focusing of charged particles," *Rev. Sci. Instr.*, vol. 20, pp. 748–750; October, 1949.
(296) O. Scherzer, "Theoretical resolution limit of the electron microscope," *Jour. Appl. Phys.*, vol. 20, pp. 20–29; January, 1949.
(297) E. G. Ramberg, "Phase contrast in electron microscope images," *Jour. Appl. Phys.*, vol. 20, pp. 441–444; May, 1949.
(298) F. W. Bishop, "Magnetic beam-splitting focusing device for the electron microscope." *Rev. Sci. Instr.*, vol. 20, pp. 532; July, 1949.

Solid-State Devices

The invention of the transistor in 1948 gave great stimulus to research in the theory of semiconductors. Development of the device and circuit applications seems to be proceeding rapidly but their characteristics are not sufficiently stabilized nor reproducible to warrant large-scale commercial application as yet.

Introductory articles on this art are:

(299) W. C. Dunlap, "Germanium, important new semiconductor," *Gen. Elec., Rev.*, pp. 9–17; February, 1949.
(300) S. J. Angello, "Semiconductor rectifiers," *Elec. Eng.*, pp. 865–872; October, 1949.
(301) J. A. Becker, "Photoeffects in semiconductors," *Elec. Eng.*, pp. 937–942; November, 1949.
(302) K. Lark-Horovitz, "Conductivity in semiconductors," *Elec. Eng.*, pp. 1047–1056; December, 1949.
(303) J. Bardeen and W. H. Brattain, "Physical principles involved in transistor action," *Phys. Rev.*, vol. 75, pp. 1208–1225; April 15, 1949.

Physical Theory and Experiment. Important new material on the properties, metallurgy, and processing of germanium and silicon was disclosed. Heat treatment, addition of chemical impurities, and nuclear bombardment methods were described for altering the type and degree of conductivity of these important semiconductors.

(304) W. E. Johnson and K. Lark-Horovitz, "Neutron irradiated semiconductors," *Phys. Rev.*, vol. 76, p. 442; August 1, 1949.
(305) J. Bardeen and W. Brattain, "Conductivity of germanium," *Phys. Rev.*, vol. 75, p. 1216; April 15, 1949.
(306) J. Bardeen and G. L. Pearson, "Electrical properties of pure silicon and silicon alloys," *Phys. Rev.*, vol. 75, pp. 865–883; March 1, 1949.
(307) M. Becker and H. Y. Fan, "Photovoltaic effect of *p-n* barriers produced in germanium by alpha and deuteron bombardment," *Phys. Rev.*, vol. 75, p. 1631; May 15, 1949.
(308) J. H. Scaff, H. C. Theuerer, and E. E. Schumacker, "*P*-type and *n*-type silicon," *Jour. of Metals.*, vol. 185, pp. 383–388; June, 1949.
(309) G. L. Pearson, J. D. Struthers, and H. C. Theuerer, "Correlation of Geiger counter and Hall effect measurements in alloys containing germanium and radioactive antimony 124," *Phys. Rev.*, vol. 75, p. 344; January 15, 1949.

Extensive work on high-back-voltage rectifiers disclosed many of the important techniques and properties of germanium rectifiers.

(310) S. Benzer, "High inverse voltage germanium rectifiers," *Jour. Appl. Phys.*, vol. 20, pp. 804–805; August, 1949.

Experiments on amplification produced by hole-flow directly through *n*-type material were demonstrated by means of a transistor having emitter and collector points on opposite sides of a thin wedge of germanium.

(311) J. N. Shive, "Double surface transistors," *Phys. Rev.*, vol. 75, pp. 689–690; February 15, 1949.
(312) J. R. Haynes and W. Shockley, "Investigation of hole injection in transistor action," *Phys. Rev.*, vol. 75, p. 691; February, 1949.

Experimental work on the external photoelectric effect of germanium and other semiconductors seems to confirm the picture presented for transistor action by measuring hole-electron distributions, contact potentials, and surface-states densities for germanium.

(313) L. Apker, E. Loft, and J. Dickey, "Photoelectric emission and contact potentials of semiconductors," *Phys. Rev.*, vol. 74, pp. 1462–1474; November. 15, 1948.

Other experiments on the behavior of holes in *n*-type germanium showed how their numbers, velocities, and lifetimes may be measured and used to modulate the conductivity of a germanium filament. A companion paper explored a number of processes encountered in previous experimental studies and brought out the nature of an advancing wave front of holes.

(314) W. Shockley, G. L. Pearson, and J. R. Haynes, "Hole injection in germanium,—quantitative studies and filamentary transistors," *Bell Sys. Tech. Jour.*, vol. 28, pp. 344–366; July, 1949.
(315) C. Herring, "Theory of transient phenomena in the transport of holes in an excess semiconductor," *Bell Sys. Tech. Jour.*, vol. 28, pp. 401–427; July, 1949.

Theoretical studies of metal-semiconductor rectifier impedances at high frequencies were presented for the case where current is carried by one type of carrier only.

A companion paper presented the theory of *p-n* rectifying barriers in a mechanically continuous piece of semiconductor where both types of carriers must be considered. Based on this theory, a *p-n-p* transistor employing no point contacts was proposed and its theory developed.

(316) J. Bardeen, "On the theory of the ac impedance of a contact rectifier," *Bell Sys. Tech. Jour.*, vol. 28, pp. 428–434; July, 1949.
(317) W. Shockley, "The theory of *p-n* junctions in semiconductors and *p-n* junction transistors," *Bell Sys. Tech. Jour.*, vol. 78, pp. 435–489; July, 1949.

Circuit Properties of Transistors and Applications. A number of papers were published that disclosed the circuit characteristics for the point-contact transistor in the form of static characteristics and equivalent circuits based on the small-signal open-circuit impedances.

Design formulas were given for gain, driving point impedances, stability margins, and noise figure for the grounded-base, grounded-emitter, and grounded-collector single-stage and iterated amplifiers. Data were presented on the large-signal properties of point-contact transistors indicating that class-A efficiencies of 20 to 35 per cent, comparable to electron-tube triodes, may be obtained. Output powers up to 200 milliwatts with less than 10 per cent distortion were reported.

The variation of gain with frequency and direct-current operating biases indicated operating power gains of about 17 decibels per stage, to frequencies of the order of 10 megacycles.

The dependence of noise figure on direct-current operating biases and frequency showed that at normal operating biases the noise figure is about 60 db at 1,000 cps, falls off inversely with the frequency and decreases with decreasing collector voltage.

Circuits were presented for several types of oscillators and negative-resistance trigger devices.

(318) J. A. Becker and J. N. Shive, "Transistor—A new semiconductor amplifier," *Elec. Eng.*, vol. 68, pp. 215–221; March, 1949.
(319) R. M. Ryder, "Type A transistor," *Bell Lab. Rec.*, vol. 27, pp. 89–93; March, 1949.
(320) W. M. Webster, E. Eberhard, and L. E. Barton, "Some novel circuits for the three-terminal semiconductor amplifier," *RCA Rev.*, vol. 10, pp. 5–16; March, 1949.
(321) R. M. Ryder and R. J. Kircher, "Some circuit aspects of transistors," *Bell. Sys. Tech. Jour.*, vol. 28, pp. 367–400; July, 1949.
(322) F. W. Lehans, "Transistor oscillator for telemetering," *Electronics*, vol. 22, pp. 90–91; August, 1949.
(323) H. J. Reich, "Transistor trigger circuits," *Rev. Sci. Instr.* vol. 20, p. 586; August, 1949.

A transistor test set was described for measuring the small-signal open-circuit impedances of transistors at 5,000 cps as a function of the direct-current operating biases.

(324) K. Lehovec, "Testing transistors," *Electroncis*, vol. 22, pp. 88–89; June, 1949.

New Semiconductor Devices. A "coaxial transistor" was announced in which the emitter and collector are on opposite sides of a thin doubly-concave disk of germanium, clearly demonstrating the transmission of holes through the body of the semiconductor.

A germanium photodiode bearing a strong physical resemblance to the coaxial transistor was described. In this device the emitter point is replaced by a beam of light such that the back impedance of the collector-point rectifier may be modulated by the light beam. This photodiode is reported to have "effective quantum efficiencies" of the order of two to four and a spectral response peaking at 1.5 microns, decreasing beyond 1.6 microns and finally cutting off at about 1.9 microns. These high effective quantum yields are believed to be due to the same current multiplication process at the collector barrier as is assumed to be operating in the transistor. Alternating-current output powers were reported of the order of one-half milliwatt per millilumen, with response flat up to at least 200 kilocycles.

Single-surface point-contact transistors using *p*-type germanium were reported. These triodes, in contrast to the first reported *n*-type, operate with collector positive and emitter negative with respect to the base. It is believed in this case that electrons are the anomalous charge carriers being injected at the emitter and being collected at the collector. Reported gains, noise figures, and power output are essentially the same as for *n*-type transistors. The frequency response is reported to be about 50 per cent higher on the average. It is pointed out that this behavior is consistent with an electron-to-hole mobility ratio of about three halves.

(325) W. E. Kock and R. L. Wallace, Jr., "Coaxial transistors," *Elec. Eng.*, vol. 68, pp. 222–223; March, 1949.
(326) J. N. Shive, "New germanium photo-resistance cell," *Phys. Rev.*, vol. 76, p. 575; August 15, 1949.
(327) W. G. Pfann and J. H. Scaff, "*P*-type germanium transistors," *Phys. Rev.*, vol. 76, p. 459; August, 1949.
(328) R. M. Ryder and R. J. Kircher, "Some circuit aspects of transistors," *Bell Sys. Tech. Jour.*, vol. 28, pp. 344–366; July, 1949.

A germanium tetrode mixer was announced having two emitters and one collector arranged in a triangle, spaced about 0.002 inch apart on a flat wafer of germanium. The signal voltage is applied to one emitter, the local oscillator voltage is applied to the other emitter, and the intermediate frequency is taken from the collector by means of a suitable resonant circuit. Conversion voltage gains of 2.5 and a corresponding conversion transconductance of 430 micromhos up to a signal frequency of 150 megacycles were reported.

Conversion power gains of one decibel are reported in some cases. Interaction between signal and local oscillator sources are much lower than that attainable in diode or triode mixers. Input signal frequencies up to 200 megacycles were described whereas the maximum intermediate frequency at which it may be used seems to agree with the maximum amplifier frequency of germanium triodes.

(329) R. W. Haegele "Crystal-tetrode mixer," *Electronics*, vol. 22, pp. 80–81; October, 1949.

The transistron, the French equivalent of the transistor, was developed by the Service des Télécommunications. It was claimed that secrecy regulations have prevented prior publication. It consists of a ceramic tube with metal ends through which the emitter and collector supports pass. A metal appendix in the middle of the ceramic tube supports the germanium crystal and provides the base contact. It is claimed that the transistron

is more stable and less subject to aging than the American transistor and this is attributed principally to the composition of the germanium. A four-transistron telephone repeater is pictured having a gain of 45 db for a pass band from 40 to 10,000 cps, which indicates somewhat lower gain per stage than for the average transistor. This may contribute to its greater stability. Other applications included a miniature 2-transistron amplifier with passive components printed on plexiglass, a similar amplifier inserted in a 4-wire telephone line, a 6-transistron radio receiver, and a miniature transmitter for 300-meter wavelengths.

(330) E. Aisberg, "Transistron = Transistor + ?" *Toute la Radio*, vol. 16, pp. 218–220; July and August, 1949.

A transistor using a thin filament of germanium (about 0.01 × 0.01 cm in cross section) having an ohmic base contact at one end, an ohmic collector at the other end, and a point contact emitter on the filament very close to the emitter was described. For *n*-type material, these electrodes are biased in a manner similar to that for the 2-point contact transistor. It was pointed out that the gain of this device results from the modulation of the high body resistance of the filament between the emitter and collector in contrast to the situation in the 2-point contact transistor where it is the high reverse impedance of the collector barrier that is modulated by hole injection from the emitter. Power gains of 15 decibels up to frequencies of the order of a megacycle were reported and noise measurements were made indicating an improvement of 10 to 15 decibels over the average 2-point contact transistor.

(331) W. Shockley, G. L. Pearson, and J. R. Haynes, "Hole injection in germanium—quantitive studies and filamentary transistors," *Bell Sys. Tech. Jour.*, vol. 28, pp. 344–366; July, 1949.
(332) W. Shockley, G. L. Pearson, M. Sparks, and W. H. Brattain, "Modulation of the resistance of a germanium filament by hole injection," *Phys. Rev.*, vol. 76, p. 459; August, 1949.

Electronic Computers

Digital Computers

Four large-scale digital computers were completed and put into operation during 1949. These represent a substantial addition to the previously completed machines.

The Mark III Calculator was completed at Harvard and the event was celebrated by an excellent four-day symposium in September on large-scale digital calculating machinery and its application. This calculator stores on magnetic drums, 200 numbers and 150 constants with an access time of 4.3 milliseconds and 4,000 numbers with longer access. Sixteen-digit decimal numbers are used in a serial, quasi-fixed-point, arithmetic unit which multiplies in 12.9 milliseconds. Another drum contains 4,000 3-address instructions. Input and output are on magnetic tape.

The Bell Computer—Model VI is a general purpose digital relay computer with an electronically or tape controlled program. The electronic program arrangement has access to combinations of several hundred semipermanent built-in standard formulas. The solution of any standard problem requires that the problem tape simply furnish the formula number and the input data of the problem. Nonstandard problems are programmed by individually coded instructions on the problem tape.

International Business Machines Corporation delivered card-programmed calculators which combine an accounting machine with an electronic calculating punch. Instructions and data are introduced on punched cards to make possible iterations and optional subroutines for involved engineering, scientific and actuarial calculations. Results appear on printed forms or punched cards.

The BINAC, completed by the Eckert-Mauchly Computer Corporation, has twin memory, arithmetic control, and checking circuits operating in complete synchronism. Each memory stores 512 30-binary-digit words in a 16-channel delay line. Multiplication time is about one millisecond. An octonary keyboard, octonary printer, and magnetic tape input and output are provided.

(333) "Mark III," *Digital Computer Newsletter*,* vol. 1, p. 4; April, 1949.
(334) E. G. Andrews, "The Bell computer, Model VI," *Elec. Eng.*, vol. 68, pp. 751–756; September, 1949.
(335) "IBM card-programmed electronic calculator," Digital Computer Newsletter,* vol. 1, p. 3; September, 1949.
(336) "Card-Programmed Electronic Calculator, Preliminary Manual of Information," International Business Machines Corp., New York, N. Y., 1949; p. 37.
(337) J. P. Eckert, Jr., J. W. Mauchly, and J. R. Weiner, "An octal system automatic computer," *Elec. Eng.*, vol. 68, p. 335; April, 1949.
(338) "The BINAC," *Digital Computer Newsletter*,* vol. 1, p. 2; April, 1949.
(339) "The BINAC," *Digital Computer Newsletter*,* vol. 1, p. 4; September, 1949.

The completion of these instruments probably means that 1949 will mark the end of the first phase of postwar computer development in which there has been much discussion of the remarkable accomplishments which are anticipated and few reports on actual achievements. However, the completed machines are still outnumbered by the projected ones.

Other major development projects now being carried out are listed in references (340) to (354).

(340) "Institute for Advanced Study Computer," *Digital Computer Newsletter*,* vol. 1, p. 2; April, 1949.
(341) "Institute for Advanced Study Computer," *Digital Computer Newsletter*,* vol. 1, p. 2; September, 1949.
(342) "Whirlwind I," *Digital Computer Newsletter*,* vol. 1, p. 4; April, 1949.
(343) "Whirlwind I," *Digital Computer Newsletter*,* vol. 1, p. 3; September, 1949.
(344) "ORDVAC," *Digital Computer Newsletter*,* vol. 1, p. 2; April, 1949.
(345) "Institute for Numerical Analysis computer," *Digital Computer Newsletter*,* vol. 1, p. 3; April, 1949.
(346) "Institute for Numerical Analysis computer," *Digital Computer Newsletter*,* vol. 1, p. 1; September, 1949.
(347) R. M. Bloch, R. V. D. Campbell, and M. Ellis, "The logical design of the Raytheon computer," and "General design considerations for the Raytheon computer," *Math. Tables and Other Aids to Computation*, vol. 3, pp. 286–295, 317–332; October, 1948.
(348) C. F. West and J. E. DeTurk, "A digital computer for scientific application," Proc. I.R.E., vol. 36, pp. 1452–1460; December, 1948. Also, minor correction, vol. 37, p. 861; August, 1949.
(349) "Raytheon computer," *Digital Computer Newsletter*,* vol. 1, p. 3; April, 1949.

* Office of Naval Research, Code 434.

(350) R. L. Snyder, "EDVAC test instrumentation," *Elec. Eng.*, vol. 68, p. 335; April, 1949.
(351) F. Koons and S. Lubkin, "Conversion of numbers from decimal to binary form in the EDVAC," *Math. Tables and Other Aids to Computation*, vol. 3, pp. 427–431; April, 1949.
(352) "EDVAC," *Digital Computer Newsletter*,* vol. 1, p. 1; April, 1949.
(353) "EDVAC," *Digital Computer Newsletter*,* vol. 1, p. 2; September, 1949.
(354) "CALDIC," *Digital Computer Newsletter*,* vol. 1, p. 3; September, 1949.

There is also considerable activity in other countries.

(355) D. R. Hartree, "Modern calculating machines," *Endeavour*, vol. 8, pp. 65–69; April, 1949.
(356) F. C. Williams and T. Kilburn, "Electronic digital computers," *Nature* (London), p. 487; September 25, 1948.
(357) M. V. Wilkes, "Programme design for a high-speed automatic calculating machine," *Jour. Sci. Instr.*, vol. 26, pp. 217–220; June, 1949.
(358) D. R. Hartree, M. H. A. Newman, M. V. Wilkes, F. C. Williams, J. H. Wilkinson, and A. D. Booth, "A discussion on computing machines," *Proc. Roy. Soc. A.*, vol. 195, pp. 265–287; December 22, 1948.

Many general surveys have been made and other descriptive material written.

(359) W. H. Bliss, "Electronic digital counters," *Elec. Eng.*, vol. 68, pp. 309–314; April, 1949.
(360) W. J. Eckert, "Electrons and computation," *Sci. Mon.*, vol. 67, pp. 315–323; November, 1948.
(361) R. Davis and A. Berry, "Electromechanical and electronic calculating devices," *Trans. S. Afr. Inst. Elec. Eng.*, vol. 40, part 3, pp. 55–73; March, 1949.
(362) L. N. Ridenour, "Mechanical brains," *Fortune*, vol. 39, pp. 109–118; May, 1949.
(363) "ENIAC," *Digital Computer Newsletter*,* vol. 1, p. 1; April, 1949.
(364) D. R. Hartree, "Calculating Instruments and Machines," University of Illinois Press, Urbana, Ill., pp. 138; 1949.
(365) R. D. Richtmyer and N. C. Metropolis, "Modern computing," *Physics Today*, vol. 2, pp. 8–15; October, 1949.

The relation between digital calculators and the brain has been the subject of considerable discussion.

(366) W. S. McCulloch, "The brain as a computing machine," *Elec. Eng.*, vol. 68, pp. 492–497; June, 1949.
(367) W. R. Ashby, "Design for a brain," *Electronic Eng.* (London), vol. 20, pp. 379–383; December, 1948.
(368) N. Wiener, "Cybernetics or Control and Communication in the Animal and Machine," John Wiley and Sons, Inc., New York, N. Y.; 1948.

The most difficult problem in the construction of a large-scale digital computers continues to be the question of how to build a memory, and the few papers written do not reflect the greatness of the effort which is being exerted.

(369) J. P. Eckert, Jr., H. Lukoff, and G. Smoliar, "A dynamically regenerated memory tube," Proc. I.R.E., vol. 37, p. 165; February, 1949. Abstract of oral paper.
(370) L. Pensak, "The graphecon—a picture storage tube," *RCA Rev.*, vol. 10, pp. 59–73; March, 1949.
(371) A. V. Haeff, "The memory tube and its application to electronic computation," *Math. Tables and Other Aids to Computation*, vol. 3, pp. 281–286; October, 1948.
(372) F. C. Williams and I. Kilburn, "A storage system for use with binary-digital machines," *Proc. IEE* (London), vol. 96, part 3, pp. 183–200; March, 1949.
(373) M. V. Wilkes and W. Renwick, "An ultrasonic memory for the EDSAC," *Electronic Eng.* (London), vol. 20, pp. 208–213; July, 1948.
(374) A. D. Booth, "A magnetic digital storage system," *Electronic Eng.* (London), vol. 21, pp. 234–238; July, 1949.
(375) F. A. Metz, Jr. and W. M. A. Andersen, "Improved ultrasonic delay lines," *Electronics*, vol. 22, pp. 96–100; July, 1949.
(376) H. Alfvén, L. Lindberg, K. G. Malmfors, T. Wallmark, and E. Åström, "Theory and application of trochotrons," *Kungl. Tekn. Hogsk., Handl.* (Stockholm), No. 22, pp. 106; 1948 (In English).
(377) I. L. Auerbach, J. P. Eckert, Jr., R. F. Shaw, and C. B. Sheppard, "Mercury delay line using a pulse rate of several megacycles," Proc. I.R.E., vol. 37, pp. 855–861; August, 1949.

The development of circuits, usually of an electronic nature, continued at a great pace. A few papers have appeared describing some of this work.

(378) K. H. Barney, "The binary quantizer," *Elec. Eng.*, vol. 68, pp. 962–967; November, 1949.
(379) R. D. O'Neal and A. W. Tyler, "Progress Report No. 1, photographic digital recorder," *Math. Tables and Other Aids to Computation*, vol. 3, pp. 444–445; April, 1949. Review of a Progress Report of Eastman Kodak Co., dated June 7, 1948.
(380) F. R. Martens, "Differential counting with reversible decade counting circuits," *Rev. Sci. Instr.*, vol. 20, pp. 424–425; June, 1949.
(381) H. J. Reich, and R. L. Ungvary, "A transistor trigger circuit," *Rev. Sci. Instr.*, vol. 20, pp. 586–588; August, 1949.
(382) D. R. Brown and N. Rochester, "Rectifier networks for multiposition switching," Proc. I.R.E., vol. 37, pp. 139–147; February, 1949.
(383) B. R. Gossick, "Predetermined electronic counter," Proc. I.R.E., vol. 37, p. 813; July, 1949.
(384) S. H. Washburn, "Relay 'trees' and symmetric circuits," *Elec. Eng.*, vol. 68, p. 958; November, 1949.
(385) A. E. Ritchie, "Sequential aspects of relay circuits," *Elec. Eng.*, vol. 68, p. 974; November, 1949.
(386) G. R. Frost, "Counting with relays," *Elec. Eng.*, vol. 68, p. 975; November, 1949.
(387) W. Keister, "Logic of relay circuits," *Elec. Eng.*, vol. 68, p. 980; November, 1949.
(388) "University of Illinois component research," *Digital Computer Newsletter*,* vol. 1, p. 4; September, 1949.
(389) E. C. Berkeley, "Giant Brains," John Wiley & Sons, Inc., New York, N. Y.; 1949.

Analogue Computers

Rapid progress has been made in analogue computers, (distinguished from digital computers in that the variables are represented as analogous voltages, shaft rotations, etc., rather than by discrete digits). The mathematical operations are performed through analogous physical relations such as addition of voltages in an electric circuit by a series connection or integration as with a planimeter. Because of the continuous character of the analogue, such computers are also referred to as the continuous-variable type.

Alternating-current networks calculators for power system problems have undergone important improvements in equipment and techniques and a number of new calculators are under construction.

The Anacom (at Westinghouse), the Northwestern University computer (Bureau of Aeronautics, Armament Division), and the California Institute of Technology analog computer are large-scale general purpose electric computers of the direct-analogue type. The Westinghouse and California Institute of Technology units were jointly developed, the former being used principally for solving transient problems involved in the electrical and mechanical design of machinery and power systems. The California Institute of Technology unit is used for a wide variety of problems, including many aircraft structural and servo problems. The Northwestern computer is composed of the basic-circuit-elements section of the Anacom, together with special electronic sections developed by the Aerial Measurements Laboratory at Northwestern University. It has been used chiefly on armament problems.

(390) W. A. Morgan, F. S. Rothe, and J. J. Winsness, "An improved ac network analyzer," paper 49-164, presented, AIEE Summer General Meeting, Swampscott, Mass., June 20–24, 1949.

* Office of Naval Research, Code 434.

(391) P. O. Bobo, "Technique of handling power system problems on a modern ac calculator," presented, AIEE Winter General Meeting, New York, N. Y., January 31, 1950.
(392) E. L. Harder and J. T. Carleton, "New techniques on the Anacom" paper 50-85, presented, AIEE Winter General Meeting, New York, N. Y., January 31, 1950.
(393) J. P. Corbett, "Summary of transformation useful in constructing analogs of linear vibration problems," AIEE paper 49-166, presented, AIEE Summer General Meeting, Swampscott, Mass., June 20–24, 1949.
(394) G. D. McCann, C. H. Wilts, and B. N. Locanthi, "Electronic techniques applied to analogue methods of computation," Proc. I.R.E., vol. 37, p. 954; August, 1949.
(395) G. D. McCann, C. H. Wilts, and B. N. Locanthi, "Application of the Cal Tech electric analog computer to nonlinear mechanics and servomechanisms," Paper 49-165, presented, AIEE Summer General Meeting, Swampscott, Mass., June 20–24, 1949.

Differential Analyzer. The earliest of the differential analyzers have been in service for a considerable number of years. The latest machine at Massachusetts Institute of Technology is electrically connected and operated through servos and a cross-bar switching system. Setups and much of the problem data are fed in through punched tapes. The usefulness of differential analyzers has been extended recently by the Michel techniques.

Meteor (Massachusetts Institute of Technology) is a large-scale, combined electric-analogue computer and flight simulator. In flight simulation a flight table is positioned at normal speed, the computer solving the aerodynamic equation of flight, i.e., simulating the action of the plane. An auto pilot can thus be tested on the flight table just as though it were in the plane under the specified flight conditions.

In straight computing, the time base is arbitrary and the computer functions as an electronic differential analyzer. Integrating amplifiers provide integration with respect to time. Multipliers are of the carrier-strain-gauge type.

Development has also continued on electronic-differential-analyzer-type computers by Reeves, Philbrick, Goodyear, and others. Over thirty of the Reeves computers are now in use, principally by the Air Force and its contractors.

(396) A. C. Cook and F. J. Maginniss, "More differential analyzer application," *Gen. Elec. Rev.*, August, 1949.
(397) G. L. Michel, "Extensions in differential analyzer technique," *Jour. Sci. Instr.*, p. 357; 1948.
(398) V. Paschkis, "Comparison of long time and short time analog computers," Paper 49-13, presented, AIEE Summer General Meeting, Swampscott, Mass., June 20–24, 1949.
(399) A. C. Hall, "A generalized analog computer for flight simulation," paper 50-48, presented, AIEE Winter General Meeting, New York, N. Y., January 31, 1950.
(400) H. S. Kirschbaum and C. E. Warren, "A method for designing pulse transformers," paper 49-198, presented, AIEE Summer General Meeting, Swampscott, Mass., June 20–24, 1949.

Facsimile

An analysis of facsimile as viewed by the armed services was presented. Facsimile applications to commercial telegraph systems have been expanded. A new recording medium utilizing selenium coatings for fine-grain reproduction has been described.

(401) "Fascimile and its place in telegraphy," *Western Union Tech. Rev.*, vol. 3, pp. 1–5; January, 1949.
(402) "The xerographic process," *Western Union Tech. Rev.*, vol. 3, pp. 43–44; January, 1949.
(403) H. F. Burkhard, "Considerations on facsimile transmission speed," AIEE Technical Paper 49-108; December, 1948.

There was developed by the Philips Research Laboratories in Holland, a very high-speed facsimile communication system employing a continuous belt scanning unit for transmission and a continuous photographic method for reception, described in five articles:

(404) "Experimental transmitting and receiving equipment for high-speed facsimile transmission,"
(a) H. Rinia, D. Kleis, and M. van Tol, "General," *Philips Tech. Rev.*, vol. 10, pp. 189–220; January, 1949.
(b) D. Kleis, F. C. W. Sloof, and J. M. Unk, "Details of the transmitter," *Philips Tech. Rev.*, vol. 10, pp. 257–264; March, 1949.
(c) F. C. W. Sloof, M. van Tol, and J. M. Unk, "Details of the receiver," *Philips Tech. Rev.*, vol. 10, pp. 265–272; March, 1949.
(d) D. Kleis and M. van Tol, "Transmission of the signals," *Philips Tech. Rev.*, vol. 10, pp. 289–298; April, 1949.
(e) D. Kleis and M. van Tol, "Synchronization of transmitter and receiver," *Philips Tech. Rev.*, vol. 10, pp. 325–333; May, 1949.

Applications of FM broadcast facsimile equipment in educational fields, particularly journalism, increased throughout the year.

(405) D. Z. Shefrin, "Talking newspaper," *The Quill*, vol. 37, p. 8010; March, 1949.

Descriptive material for broadcast engineers appeared as a brief treatment of systems operation.

(406) "Facsimile," Engineering Handbook, National Association of Broadcasters, fourth edition, section 2, article 6; 1949.

A book related the experiences of two newspapermen in installing and operating a multi-edition broadcast facsimile publication in Florida over a three-year period.

(407) Lee Hills and T. J. Sullivan, "Facsimile," McGraw-Hill Book Co., New York, N. Y.; 1949.

Another book, contained data on circuit analysis and equipment as designed and fabricated in the United States.

(408) C. R. Jones, "Facsimile," Murray Hill Books, Inc., New York, N. Y.; 1949.

The further interest of government agencies in weather map distribution by facsimile was followed by continued development and production of improved equipments.

(409) "New facsimile recorder," *Tel. and Tel. Age*, vol. 67, pp. 10, 12; January, 1949.

One development of significance was the introduction of a high-speed system for the transmission of graphic material.

(410) "Ultrafax," *Electronics*, vol. 22, pp. 77–79; January, 1949.
(411) D. S. Bond and V. J. Duke, "Ultrafax," *RCA Rev.*, vol. 10, pp. 99–115; March, 1949.

Industrial Electronics

The applications of electronics to the solution of industrial problems have grown at an accelerated rate in 1949. A conference held in April in Buffalo, N. Y., focused attention on problems of greater reliability. Papers were presented on the application of electron tubes to motor control, electronic regulators, ac power control, life tests of vacuum tubes and maintenance problems of tubes in industry, and regulation of supply voltage needs. The inadequacies of tube ratings, needed improvements in tube characteristics and ratings and use of capacitors in electronic circuits, etc., were also dis-

cussed. The transactions of this conference are available in limited quantities.

(412) Digests of papers presented at Conference on Electron Tubes in Industry, *Elec. Eng.*, vol. 68, pp. 525–530; June, 1949.

Modulation Systems

In the field of abstract communications theory, the application of the geometry of n-dimensional space led to expressions for the capacity of a system for transmitting information in terms of upper and lower bounds which may be converted to an equality when the system is adequately specified. Similar results were obtained for the rate of generating information by a message source. In general these results are included in the statements that:

$$W \log_2 \frac{P + N_1}{N_1} \leqq C \leqq W \log_2 \frac{P + N}{N}$$

$$W \log_2 \frac{\overline{Q}}{N_2} \leqq R \leqq W \log_2 \frac{Q}{N_2},$$

where

W = the bandwidth of the system or the source
P = the average power handling capacity of the system
N_1 = the average power of a white thermal noise source having the same entropy as the actual noise on the system
N = the average noise power on the system
C = the capacity of the system for transmitting information
$\overline{Q}$ = the average entropy power of the message source
Q = its average power
N_2 = the mean-square permissible error in transmitting the message and
R = the rate of generating information by the source.

It is always possible to encode the message so that transmission is possible with errors reduced to any desirable value if $R \leqq C$, but it is not possible to do so if $R > C$.

(413) C. E. Shannon, "Communication in the presence of noise," Proc. I.R.E., vol. 37, pp. 10–21; January, 1949.

By a similar approach, it was shown that under assumptions which amount to peak limited noise the performance of a coded type system is expressed by:

$$\frac{\log_2\left(1 + \frac{S}{N}\right)}{\log_2\left(1 + \frac{C}{N}\right)} = \frac{B}{f_c},$$

while for a system not involving coding

$$\frac{\left(1 + \frac{S}{N}\right)}{\left(1 + \frac{C}{N}\right)} = \frac{B}{f_c}$$

where in both cases S/N is the received signal-to-noise ratio, C/N is the system carrier-to-noise ratio, B is the system bandwidth and f_c is the message bandwidth.

The transmission efficiencies (the rate of transmitting information over a given system compared to the rate at which it could have been transmitted by a single sideband system over the same medium) for several commonly used modulation systems were calculated.

(414) W. G. Tuller, "Theoretical limitations on the rate of transmission of information," Proc. I.R.E., vol. 37, pp. 468–478; May, 1949.
(415) A. G. Clavier, "Evaluation of transmission efficiency according to Hartley's expression of information content," *Elec. Commun.*, vol. 25, pp. 414–420; December, 1948.

An analysis of the significance of signal bandwidth and frequency occupancy in relation to other transmission factors such as power, noise, interference, and overall performance was carried out for eight types of multiplex systems under assumed operating conditions. The eight systems are the possible combinations of PAM, PPM, PCM, or FDM primary multiplex with either AM or FM the final carrier. The results were summarized in a set of charts and tables.

(416) W. R. Bennett and C. B. Feldman, "Bandwidth transmission performance," *Bell. Sys. Tech. Jour.*, vol. 28, pp. 490–595; July, 1949.

In the field of pulse modulation several papers were written describing the principles of the method from various elementary points of view.

(417) P. Breant, "Time and amplitude pulse modulation," *Ann. Telecommun.*, vol. 3, pp. 309–316; October, 1948.
(418) E. M. Deloraine, "Pulse modulation," Proc. I.R.E., vol. 37, pp. 702–705; June, 1949.
(419) J. R. Hyneman, "Pulse modulation systems," *Western Union Tech. Review*, vol. 3, pp. 69–76; April, 1949.
(420) R. B. Long, "Application of pulse modulation to multiplex communication systems," *Proc. IRE (Australia)*, vol. 10, pp. 10–17; January, 1949.
(421) H. Rindfleisch, "On the stage of development of pulse code modulation," *Fernmeldtech. Z.*, vol. 2, pp. 25–26; January, 1949.

Two new pulse modulation systems were described. One modulates both the amplitude of the pulses and the carrier frequency, thereby producing $2N$ channels with a synchronizing and gating system which is required to produce only N gates. The second reduced the bandwidth of the transmitting medium to the minimum value required to transmit the information, and then equalized the system at the receiver by a transversal type equalizer so as to eliminate intersymbol interference. The adjustment of this equalizer seems to be quite simple.

(422) H. Goldberg and C. C. Bath, "Multiplex employing pulse-time and pulsed-frequency modulation," Proc. I.R.E., vol. 37, pp. 22–28; January, 1949.
(423) W. P. Boothroyd and E. M. Creamer, Jr., "Time division multiplexing system," Proc. I.R.E., vol. 68, pp. 583–588; July, 1949.

A statistical study of the effect of white thermal noise on a PCM system showed that the signal-to-noise ratio in the output of such a system when expressed in db is equal to the signal-to-noise ratio in the input expressed as a power ratio.

(424) A. G. Clavier, P. F. Panter, and W. Dite, "Signal-to-noise ratio improvement in a PCM system," Proc. I.R.E., vol. 37, pp. 355–359; April, 1949.

Navigation Aids

Interest continued in phase-sensitive devices based upon the synthetic rotation of an antenna array. Be-

cause of the high rotational velocities desired, the effective rotation is produced electronically by suitably commutating a fixed receiving array (for direction-finder applications), or by driving a fixed transmitting array with polyphase voltages (for omnirange-beacon applications).

Synthetic-rotation has long been used in ionospheric polarization measurements, yielding sum-and-difference frequencies with amplitudes dependent upon polarization components. Applications to navigation problems were based on a variety of phase-meters, having essentially instantaneous response, together with a 360-degree uniform scale. Rotation causes the envelope of the received signal to be sinusoidally modulated, usually at 30 cycles. This is compared with a reference voltage of similar frequency, having a fixed and known phase-relation with respect to the source of "rotation."

(425) E. K. Sandeman, "Spiral-phase fields," *Wireless Eng.*, vol. 26, pp. 96–105; March, 1949.
(426) C. W. Earp and R. M. Godfrey, "Radio direction-finding by the cyclical differential measurement of phase," *Elec. Commun.*, vol. 26, pp. 52–75; March, 1949.
(427) Gunnar Wennerberg, "VHF direction-finder for light planes," *Electronics*, vol. 22, p. 118; August, 1949.

Interest continued in distance-measuring-equipment (DME) and related subjects. Papers in this field were chiefly concerned with incidental refinements appearing in the engineering design offered by a particular supplier or national research group.

(428) V. D. Burgmann, "Distance-measuring equipment for aircraft navigation," (Radio Section) *Proc. IEE*, vol. 96, pp. 395–402; September, 1949.
(429) Charles J. Hirsh, "Pulse-multiplex system for distance measuring equipment," Proc. I.R.E., vol. 37, pp. 1236–1242; November, 1949.
(430) L. B. Hallman, "Considerations in the design of a universal beacon system," Proc. I.R.E., vol. 36, pp. 1526–1529; December, 1948.

The utility of the Decca system was extended and applied to hydrographic survey and oil exploration in the Persian Gulf.

(431) "The Decca navigator system with Lane identification," *The Engineer*, vol. 187, pp. 101–102; January 28, 1949.
(432) "The Decca navigator system," *Engineering*, vol. 167, pp. 439–442; May 13, 1949.
(433) "Decca navigator chain for oil survey," *The Engineer*, vol. 187, p. 287; March 11, 1949.
(434) M. P. Giroud and M. L. Couillard, "Le Navigateur 'Decca,'" *L'Onde Electrique*, vol. 29, pp. 5–20; January, 1949.

A number of papers relate to operational experience and plans for the improvement of navigational aids, including Ground Control Approach and Instrument Landing Systems.

(435) "'ABAS' instrument landing system," *The Engineer*, vol. 187, p. 479; April 29, 1949.
(436) "Aircraft landing aids," *The Engineer*, vol. 187, p. 679; June 24, 1949.
(437) M. A. Chaffee and R. B. Corby, "What we learned from the Berlin airlift," *Electronics*, vol. 22, pp. 78–83; August, 1949.
(438) Annual Reports of the Technical Committees, Institute of Navigation; August 16, 1949.

The "five-year-interim-plan" and the "fifteen-year-plan" set forth by the Radio Technical Commission for Aeronautics were well publicized.

(439) P. C. Sandretto, "System of air navigation and traffic control recommended by the radio technical commission for aeronautics," *Elec. Commun.*, vol. 26, pp. 17–27; March, 1949.
(440) "Radio Aids to Navigation (Symposium)," Proc. I.R.E., vol. 37, pp. 169–170; February, 1949.
(441) "The program of new aids to air navigation," Proc. I.R.E., vol. 37, pp. 1041–1042; September, 1949.

Several writers have performed a useful liaison service by describing current trends in other countries.

(442) "Radio distance-measuring equipment for aerial navigation," *Engineering*, vol. 167, p. 187; February 25, 1949.
(443) Pierre David, "Introduction a la radionavigation," *L'Onde Elec.*, vol. 29, pp. 3–4; January, 1949.
(444) Lt. Guigonis, "La radionavigation aerienne en temps de guerre," *L'Onde. Elec.*, vol. 29, pp. 21–25; January, 1949.
(445) A. Violet, "Aides radioelectriques a l'approche et a l'atterrissage controle du trafic aerien," *L'Onde Elec.*, vol. 29, pp. 91–109; March, 1949.
(446) H. Portier, "Les Radiophares du type 'Consol,'" *L'Onde Elec.*, vol. 29, pp. 57–65; February, 1949.
(447) P. Besson, "Le systeme 'OBOE,'" *L'Onde Elec.*, vol. 29, pp. 351–367; October, 1949.

Isolated topics included description of an offset-course computer, theory of an improved cable system for possible use in defining a glide-slope description of the elaborate telephone network used in air-traffic-control, and an extensive discussion of the theory of errors, in its application to the evaluation of navigational data.

(448) F. J. Gross, "The course-line computer for radio navigation of aircraft," Proc. I.R.E., vol. 37, pp. 830–834; July, 1949.
(449) S. Ostridow, "Le cable d'atterrisage et ses applications modernes possibles," *L'Onde Elec.*, vol. 29, pp. 255–267; June, 1949.
(450) W. O. Arnold, "The 111A key equipment for air traffic control," *Bell Lab. Rec.*, vol. 27, pp. 394–398; November, 1949.
(451) P. F. Duncan, "Theory of error distribution," *Wireless Eng.*, vol. 26, pp. 49–52; February, 1949.

Nuclear Science

General

Radio engineers have developed an increased awareness of the impact of nuclear energy on their profession. An Institute Professional Group on Nuclear Science was established in addition to the already active Nuclear Studies Committee. An RMA Committee on Nuclear Instrumentation was also formed. The IRE Professional Group on Nuclear Science sponsored jointly with the American Institute of Electrical Engineering a Conference on Electronic Instrumentation in Nucleonics and Medicine. The Atomic Energy Commission sponsored several meetings on instrumentation: at Oak Ridge, on scintillation counters; at Fort Monmouth, on ionization chambers; and at the Naval Research Laboratory, on Geiger Tubes.

A series of eleven articles in Electrical Engineering were combined in a single publication entitled "Elements of Nucleonics for Engineers," published in March, 1949, by the American Institute of Electrical Engineering. For those seriously interested in this field, attention is called to a bi-weekly publication entitled "Nuclear Science Abstracts" published by Atomic Energy Commission Document Sales Agency, P. O. Box 62, Oak Ridge, Tenn. A number of general survey articles appear below.

(452) W. E. Shoupp, "Electronics in nuclear physics," Proc. I.R.E., vol. 36, pp. 1518–1526; December, 1948.
(453) K. Z. Morgan, "Instrumentation in the field of health physics," Proc. I.R.E., vol. 37, pp. 74–82; January, 1949.
(454) J. A. Victoreen, "Ionization chambers," Proc. I.R.E., vol. 37, pp. 189–199; February, 1949.

(455) J. A. Victoreen, "Electrometer tubes for the measurement of small currents," Proc. I.R.E., vol. 37, pp. 332–441; April, 1949.
(456) R. A. Millikan, "Atomic energy—its release, utilization, and control," Proc. I.R.E., vol. 37, pp. 545–547; May, 1949.
(457) L. F. Curtis, "Radioactive standards and methods of testing instruments used in the measurement of radioactivity," Proc. I.R.E., vol. 37, pp. 913–922; August, 1949.
(458) T. W. Dietze and T. M. Dickinson, "Electronics applied to the betatron," Proc. I.R.E., vol. 37, pp. 1171–1178; October, 1949.
(459) A. P. Schreiber, "Radioisotopes for industry," *Electronics*, vol. 22, pp. 90–95; January, 1949.
(460) G. W. Morgan, "Surveying and monitoring of radiation from radioisotopes," *Nucleonics*, vol. 4, pp. 24–37; March, 1949.
(461) "Nuclear instrument handbook," *Nucleonics*, vol. 4, pp. 100–152; May, 1949.
(462) H. H. Goldsmith, "Bibliography on radiation protection," *Nucleonics*, vol. 4, pp. 62–69; June, 1949.

Instruments

With 42 different manufacturers engaged in the production of nuclear instruments and components, there were many new and improved instruments for radiation detection put on the market during this year, including two radioactive thickness gauges. This marks one of the first instances of the commercial use of radioactivity in process control.

(463) J. R. Carlin, "Radioactive thickness gauge for rapidly moving materials," *Electronics*, vol. 22, pp. 110–113; October, 1949.
(464) W. E. Glenn, Jr., "Pulse height distribution analyzer," *Nucleonics*, vol. 4, pp. 50–61; June, 1949.
(465) W. C. Elmore, "Fast pulse amplifiers for nuclear research," *Nucleonics*, vol. 5, pp. 48–55; September, 1949.
(466) W. F. Hornyak, T. Lauritsen, and V. K. Rasmussen, "Gamma-ray measurements with a magnetic lens spectrometer," *Phys. Rev.*, vol. 76, pp. 731–738; September 15, 1949.
(467) W. Bernstein and R. Ballentine, "Methane flow beta-proportional counter," *Rev. Sci. Instr.*, vol. 20, pp. 347–348; May, 1949.
(468) F. H. Martens, "Differential counting with reversible decade counting circuits," *Rev. Sci. Instr.*, vol. 20, pp. 424–425; June, 1949.

Microwave spectroscopy continued to be an active field but results for the most part were of interest to physicists, and not radio engineers. One exception was the development of the so-called "atomic clock" which utilizes an absorption frequency (23,870.1 megacycles) of ammonia to furnish frequency stabilization.

(469) "The atomic clock," *Tech. Bull. Nat. Bur. Stand.*, vol. 33, pp. 17–24; February, 1949.

Ionization Chambers

While ionization chambers remain a very important factor in measuring radiant energy, there was little published during the past year.

(470) C. G. Montgomery and D. D. Montgomery, "Coincident bursts in small ionization chambers," *Phys. Rev.*, vol. 75, p. 980; March 15, 1949.
(471) N. M. Blachman, "Counting volume of a cylindrical ionization chamber," *Rev. Sci. Instr.*, vol. 20, pp. 477–479; July, 1949.
(472) B. Rossi and H. H. Staub, "Ionization Chambers and Counters: Experimental Techniques," McGraw-Hill Book Co., New York, N. Y.; 1949.

Geiger Tubes

The continued wide use of Geiger tubes for measurement purposes has led to numerous brief reports on various peculiarities in their operation. The feeling in some quarters that the discharge processes within the tubes are poorly understood received support in a paper by George Kelley of Oak Ridge presented at the Naval Research Laboratory conference and not yet published. Kelley reported experiments indicating that at least 20 per cent of the current flow in the Geiger discharge is contributed by electrons and not ions as has heretofore been believed.

(473) H. Friedman, "Geiger counter tubes," Proc. I.R.E., vol. 37, pp. 791–808; July, 1949.
(474) H. den Hartog, "Speed of operation of Geiger-Müller counters," *Nucleonics*, vol. 5, pp. 33–47; September, 1949.
(475) H. R. Crane, "Discharge of a Geiger counter at voltages above the plateau," *Phys. Rev.*, vol. 75, p. 985; March 15, 1949.
(476) O. M. Parkash, "On temperature dependence of counter characteristics in self-quenching G-M counters," *Phys. Rev.*, vol. 76, p. 568; August 15, 1949.
(477) J. D. Louw and S. M. Naude, "Spurious counts in Geiger counters and the pre-treatment of the electrodes," *Phys. Rev.*, vol. 76, p. 571; August 15, 1949.
(478) S. A. Korff and A. D. Krumbein, "Tests of self-regenerating fillings for Geiger counters," *Phys. Rev.*, vol. 76, p. 1412; November 1, 1949.
(479) W. B. Mann and G. B. Parkinson, "Geiger-Mueller counting unit and external quenching equipment for the estimation of C^{14} in carbon dioxide," *Rev. Sci. Instr.*, vol. 20, pp. 41–47; January, 1949.
(480) C. D. Thomas, "Counter pulse shape," *Rev. Sci. Instr.*, vol. 20, pp. 147–149; March, 1949.
(481) M. Ter-Pogossian, J. E. Robinson, and J. Townsend, "Pressure regulated thin window Geiger-Mueller counter," *Rev. Sci. Instr.*, vol. 20, pp. 289–290; April, 1949.
(482) M. A. Guimaraes and P. A. Sampaio, "Circuit for the study of the operation of the Geiger-Müller counter," *Rev. Sci. Instr.*, vol. 20, pp. 485–488; July, 1949.
(483) H. E. Newell and E. C. Pressly, "Counting with Geiger counters," *Rev. Sci. Instr.*, vol. 20, pp. 568–572; August, 1949.

Crystal Counters

Developments in this field, as shown by the lack of published articles, seemed to indicate that some of the early hopes for the widespread utilization of crystal counters, particularly diamonds, might not be realized. A new type of crystal counter was described by R. M. Lichtenstein at the Joint IRE-AIEE Symposium. He used crystals of alkali halides, such as KBr, which became discolored upon exposure to radiation. They can be bleached by exposure to strong light, the bleaching resulting in a voltage pulse appearing across electrodes on the crystal faces.

(484) R. Hofstodter, "Crystal counters," *Nucleonics*, vol. 4, part I, pp. 2–27; April, 1949. Part II, pp. 29–43; May, 1949.
(485) R. R. Newton, "Space charge effects in bombardment conductivity through diamond," *Phys. Rev.*, vol. 75, pp. 234–245; January 15, 1949.
(486) A. J. Ahearn, "Search for crystals that exhibit conduction pulses under alpha-particle bombardment," *Phys. Rev.*, vol. 75, p. 1966; June 15, 1949.
(487) K. A. Yamakawa, "Suggested slow neutron crystal counter," *Phys. Rev.*, vol. 75, p. 1774; June 1, 1949.

Scintillation Counters

There was steady progress in the scintillation counter field. One instrument manufacturer announced the production of a commercial scintillation counter. Considerable impetus was given to this field by the production of an electron multiplier tube, type 5819, designed specifically for scintillation counting.

(488) J. W. Coltman, "The scintillation counter," Proc. I.R.E., vol. 37, pp. 671–682; June, 1949.
(489) G. A. Morton and J. A. Mitchell, "Performance of 931-A type multiplier as a scintillation counter," *Nucleonics*, vol. 4, pp. 16–23; January, 1949.
(490) G. A. Morton and K. W. Robinson, "A coincidence scintillation counter," *Nucleonics*, vol. 4, pp. 25–29; February, 1949.

(491) N. H. Jordan and P. R. Bell, "Scintillation counters," *Nucleonics*, vol. 5, pp. 30–41; October, 1949.
(492) B. Cassen, C. W. Reed, L. Curtis, and L. Baurmash, "Low-rate alpha scintillation counter," *Nucleonics*, vol. 5, pp. 55–59; October, 1949.
(493) H. G. Gittings, R. F. Taschek, A. R. Ronzio, E. Jones, and W. J. Masilun, "Relative sensitivities of some organic compounds for scintillation counters," *Phys. Rev.*, vol. 75, p. 205; January 1, 1949.
(494) W. C. Elmore and R. Hofstadter, "Temperature dependence of scintillations in sodium iodide crystals," *Phys. Rev.*, vol. 75, p. 203; January 1, 1949.
(495) H. Kallmann, "Quantitative measurements with scintillation counters," *Phys. Rev.*, vol. 75, p. 623; February 15, 1949.
(496) R. Hofstadter, "Detection of gamma-rays with thallium-activated sodium iodide crystals," *Phys. Rev.*, vol. 75, p. 796; March 1, 1949.
(497) E. J. Schillinger, Jr., B. Waldman, and W. C. Miller, "Scintillation counting with chrysene," *Phys. Rev.*, vol. 75, p. 900; March 1, 1949.
(498) G. C. Hanna and B. Pontecorvo, "Fluorescence of anthracene excited by high energy radiation," *Phys. Rev.*, vol. 75, p. 983; March 15, 1949.
(499) W. J. MacIntyre, "Decay of scintillations in calcium fluoride crystals," *Phys. Rev.*, vol. 75, p. 1439; May 1, 1949.
(500) G. F. J. Garlick and R. A. Fatehally, "Measurement of particle energies with scintillation counters," *Phys. Rev.*, vol. 75, p. 1446; May 1, 1949.
(501) W. S. Koski and C. O. Thomas, "Scintillations produced by α-particles in a series of structurally related organic crystals," *Phys. Rev.*, vol. 76, p. 308; July 15, 1949.
(502) L. B. Robinson and J. R. Arnold, "Scintillation counter I. The existence of plateaus," *Rev. Sci. Instr.*, vol. 20, pp. 549–552; August, 1949.
(503) J. D. Graves and J. P. Dyson, "Scintillation counter for laboratory counting of alpha-particles," *Rev. Sci. Instr.*, vol. 20, pp. 560–565; August, 1949.

Piezoelectric Crystals

A new standards report on piezoelectricity was issued by the Institute.

(504) "Standards on Piezoelectric Crystals, 1949," PROC. I.R.E., vol. 37, pp. 1378–1395; December, 1949.

Books

The following books have appeared.

(505) W. J. Fry, J. M. Taylor, and B. W. Henvis, "Design of Crystal Vibrating Systems for Projectors and Other Applications," Dover Publications, Inc., New York, N. Y.; 1948.
(506) W. Herzog, "Siebschaltungen mit Schwingkristallen," (Filter Circuits with Vibrating Crystals), Dieterich'sche Verlagsbuchhandlung, Inh. W. Klemm GMBH, Wiesbaden; July, 1949.
(507) K. S. Van Dyke, "A Manual of Piezoelectric Data," Part 2 of Fifth Semi-Annual Report on Contract W28-003 sc-1556, Wesleyan University to the U. S. Signal Corps; January 20, 1948; Second Volume, Part 2 of Sixth Semi-Annual Report; July 28, 1948.

There appeared a compilation of papers by authors in various countries on theory of growth, nucleation and normal growth, abnormal and modified growth, mineral synthesis, and other technical aspects together with papers on quartz, ammonium dihydrogen phosphate, and other important piezoelectric crystals.

(508) "Crystal Growth," Discussions of the Faraday Society, No. 5, 1949, Gurney and Jackson, London; 1949.

Fundamental Theory

On the theoretical side, progress has been made in correlating the piezoelectric properties with structural and other characteristics.

(509) S. Bhagavantam and D. Suryanarayana, "Crystal symmetry and physical properties: application of group theory," *Acta Crystallographica*, vol. 2, part 1, pp. 21–26; March, 1949.
(510) K. Huang, "Lattice theory of dielectric and piezoelectric constants in crystals," *Phil. Mag.*, vol. 40, pp. 733–747; July, 1949.
(511) J. J. Kyame, "Wave propagation in piezoelectric crystals," *Jour. Acous. Soc. Amer.*, vol. 21, pp. 159–167; May, 1949.
(512) B. D. Saxena and K. G. Srivastava, "Calculation of the piezoelectric constants of α-quartz on Born's theory," *Indian Jour. Phys.*, vol. 22, pp. 475–482; November, 1948.
(513) B. D. Saxena and K. G. Srivastava, "New method of calculating the piezoelectric constants of α-quartz," *Proc. Indian Acad. Sci.*, A, 28, 423–436; November, 1948. (*Phys. Abstr.*, vol. 52, p. 397; July, 1949.)
(514) B. D. Saxena and K. G. Srivastava, "Variation of the piezoelectric constants of α-quartz with temperature," *Proc. Indian Acad. Sci.*, A, 28, pp. 437–446; November, 1948. (*Phys. Abstr.*, vol. 52, p. 397; July, 1949.)
(515) S. Zerfoss and L. R. Johnson, "Crystal chemical relations in inorganic piezoelectric materials," *Amer. Mineralogist*, vol. 34, pp. 61–67; January-February, 1949.

Synthetic Crystals and Detwinning

The long search for methods of growing quartz crystals artificially made good progress. Crystals of 150 grams were grown from 12-gram seeds,[1] and the growth in a single bomb of 650 grams of quartz in 13 days, distributed over 30 seeds,[2] was reported. Meanwhile, the detwinning of natural quartz crystals—which, in any case, is possible only with electrical twinning—seemed to be beset with technical difficulties. It is fortunate that EDT (ethylene diamine tartrate) crystals are relatively easy to grow, and that they are better than quartz for some purposes.

(516) C. F. Booth and J. P. Johns, "The development of quartz crystal production," *Jour. IEE* (London), vol. 84 (16), Part 3A, pp. 899–911; 1947.
(517) E. Buehler and A. C. Walker, "Synthetic crystals of quartz," *Bell Lab. Rec.*, vol. 26, pp. 384–385; September, 1948.
(518) I. Franke and M. H. de Longchamp, "Production of large artificial quartz crystals," *Compt. Rend. Acad. Sci.* (Paris), vol. 228, pp. 1136–1137; March 28, 1949.
(519) D. R. Hale, "Artificial quartz crystals," *Quarterly Progress Report No. 9*, The Brush Development Co.; July 15, 1948.
(520) W. Parrish, "Techniques for detwinning electrically twinned quartz," *Technical Information Pilot*, p. 781; July 20, 1949.
(521) A. C. Walker and G. T. Kohman, "Growing crystals of Ethylene diamine tartrate," *Trans. AIEE*, vol. 67, 565–570; 1948.

Piezo-oscillators, Equivalent Networks, and Techniques

Oscillator circuits for great constancy of frequency have been described, especially of bridge-stabilized types. Piezo-oscillator circuits have been investigated further with respect to variability of frequency. A combination of coil and condenser associated with the crystal for widening the range of frequency control has been proposed.

(522) J. L. Creighton, H. B. Law, and R. J. Turner, "Crystal oscillators and their application to radio transmitter control," *Jour. IEE* (London), vol. 94, Part 3A, pp. 331–344; 1947; PROC. I.R.E., vol. 36, p. 1182; September, 1948.
(523) W. Herzog, "Oszillatorschaltungen hoher Frequenzkonstanz," (Oscillator circuits of very constant frequency), *A. E. Ü.*, vol. 3, pp. 203–207; 1949.
(524) W. Herzog, "Verfahren zur Veränderung der Resonanzfrequenz von Kristalloszillatoren," (Means for varying the resonant frequency of crystal oscillators), *A. E. Ü.*, vol. 2, pp. 153–163; 1948.
(525) W. Herzog, "Die Frequenzveränderung eines Kristallbrückenoszillators," (Frequency variation of a crystal bridge oscillator), *A. E. Ü.*, vol. 2, pp. 357–361; June, 1948.
(526) H. B. Meahl, "Absolute accuracy. Primary frequency standard," *Proc. NEC*, vol. 4, pp. 446–450; 1948. And PROC. I.R.E., vol. 37, p. 1226; October, 1949.

[1] Unpublished data from (521).
[2] Unpublished data from (519).

(527) A. E. Miller, "Frequency-control units," Proc. I.R.E., vol. 37, p. 167; February, 1949.
(528) H. Stanesby and P. W. Fryer, "Variable-frequency crystal oscillators," *Jour. IEE* (London), vol. 94, part 3A, pp. 368–378; 1947. Also, Proc. I.R.E., vol. 36, p. 1182; September, 1948. (Abstracts and References)

A theoretical treatment of the effect of mechanical loading on resonant and antiresonant frequencies has been made. The equivalent network of the Curie double strip (two thin bars cemented together, for flexural vibrations) has been derived. Considerable attention is being given to the study of coupling between modes and the effect of partial plating, and of a spherical or cylindrical contour on the vibrating faces.

(529) W. J. Fry, "Low loss crystal systems," *Jour. Acous. Soc. Amer.*, vol. 21, pp. 29–34; January, 1949.
(530) B. A. Mamyrin and L. N. Sosnovkin, "The effect of spurious resonances and parallel losses on the equivalent parameters of quartz crystals," *Zh. Tekh. Fiz.*, vol. 18, pp. 955–958; July; 1948 (In Russian). Also, Proc. I.R.E., vol. 37, p. 329; March; 1949.
(531) E. J. Post, "The equivalent circuit of the Curie double strip," *Appl. Sci. Res.*, B1, pp. 168–180; 1948; (*Phys. Abstr.*, vol. 52, p. 236; May, 1949).
(532) K. S. Van Dyke, E. A. Pendleton, and G. D. Gordon, "The Equivalent Circuit of Partially Plated Thickness-Shear Piezoelectric Resonators," Presented Williams College Meeting of New England Section of the American Physical Society, October 22, 1949; (Abstract in a forthcoming issue of *Phys. Rev.*).
(533) R. S. Bever, V. E. Bottom, and L. R. Weber, "Factors which affect the rate of change of equivalent reactance of the crystal unit with frequency," *Quarterly Progress Rept. No. 4*, June 30, 1948; *Quarterly Progress Rept. No. 5*, September 15, 1948; Colorado Agriculture and Mechanical College; *Technical Information Pilot*, pp. 520–521; April 1, 1949.

Vibrational characteristics have been examined by a probing device, and improved by annealing. Devices have been described for measuring the equivalent resistance of a vibrating crystal.

(534) C. R. Mingins, C. A. Stevens, and D. W. MacLeod, Jr., "Studies of the vibrational characteristics of a piezoid," *Phys. Rev.*, vol. 76, p. 467; August 1, 1949.
(535) A. C. Prichard, M. A. A. Druesne, and D. G. McCaa, "Increase in Q-value and reduction of aging of quartz crystal blanks," *Jour. Appl. Phys.*, vol. 20, p. 1011; October, 1949.
(536) L. A. Rosenthal and T. A. Peterson, Jr., "The measurement of the series-resonant resistance of a quartz crystal," *Rev. Sci. Instr.*, vol. 20, pp. 426–429; June, 1949.

Measurements of Crystal Properties

Measurements of piezoelectric constants of potassium hydrogen arsenate (KDA) and their temperature dependence have been made by balancing static mechanical displacements piezoelectrically produced against a quartz standard. Thirty-five different water-soluble crystals have been tested and compared. A measurement has been made of the piezoelectric properties of alpha and of beta quartz over a wide temperature range. Other properties of piezoelectric crystals have also had attention, namely the elastic properties of Rochelle salt by an ultrasonic-pulse technique, the pyroelectric properties of lithium sulfate monohydrate, and the electro-optical properties of ammonium dihydrogen phosphate (ADP).

The measurement of the piezoelectric coefficients of ethylene diamine tartrate were made at the British Post Office.

(537) R. Bechmann and A. C. Lynch, "Piezoelectric coefficients of ethylene diamine tartrate," *Nature* (London), vol. 163, pp. 915–916; June 11, 1949.
(538) R. O'B. Carpenter, "Dynamic measurement of electro-optic coefficients in ADP crystals," *Phys. Rev.*, vol. 76, p. 467; August 1, 1949.
(539) B. H. Billings, "The electro-optic effect in uniaxial crystals of the type XH_2PO_4," *Jour. Opt. Soc. Amer.*, vol. 39, pp. 797–808; October, 1949.
(540) R. K. Cook and P. G. Weissler, "Measurement of the piezoelectric constants of alpha- and beta-quartz," *Phys. Rev.*, vol. 75, p. 1283; April 15, 1949.
(541) H. Jaffe, "Compressional piezoelectric coefficients of monoclinic crystals," *Phys. Rev.*, vol. 73, p. 1467; June 15, 1948.
(542) H. Jaffe, "Study of Synthetic Water Soluble Piezoelectric Crystals for Frequency Control," *Final Report*, April 1, 1948, The Brush Development Company; *Technical Information Pilot*, p. 924, September 9, 1949.
(543) H. Jaffe, "Primary and secondary pyroelectric effect in lithium sulfate monohydrate," *Phys. Rev.*, vol. 75, p. 1625; May 15, 1949.
(544) T. Niemiec, "A method of measurement of small periodic displacements and its application to determining the piezoelectric constants of potassium dihydrogen arsenate," *Phys. Rev.*, vol. 75, pp. 215–216; January 1, 1949.
(545) W. J. Price, "Ultrasonic measurements on Rochelle salt crystals," *Phys. Rev.*, vol. 75, pp. 946–952; March 15, 1949.

Barium Titanate

$BaTiO_3$ ceramics are being used for resonators, phonograph pickups, and microphones. Transducers for underwater work are described, and it is found that great improvement is provided by the addition of a few per cent of lead titanate. Another promising application is for flexural films with high dielectric constant, for which SiO_2 is used as the binding agent.

(546) A. I. Dranetz, G. N. Howatt, and J. W. Crownover, "Barium titanates as circuit elements," *Tele-Tech.*, vol. 8, pp. 29–31, 53, 54; April, 1949; pp. 28–30, 54, 56, 57; May, 1949; and pp. 36–39, 52, 53; June, 1949.
(547) C. H. Allen, "A small high-frequency barium titanate microphone," *Bull. Acous. Soc. Amer.*, p. 11; November 17–19, 1949.
(548) M. U. Cohen, and others, "A study of high dielectric constant films for high temperature operation," *Final Report*, July 1, 1946, to June 30, 1948, Balco Research Laboratories, July 15, 1948; *Technical Information Pilot*, p. 373; December 31, 1948.
(549) H. L. Donley, "Barium titanate and barium strontium titanate resonators," *RCA Rev.*, vol. 9, pp. 218–228; June, 1948.
(550) G. N. Howatt, J. W. Crownover, and A. Dranetz, "New synthetic piezoelectric material," *Electronics*, vol. 21, pp. 97–99; December, 1948.
(551) H. W. Koren, "Application of activated ceramics to transducers," *Jour. Acous. Soc. Amer.*, vol. 21, pp. 198–201; May, 1949.
(552) W. P. Mason, "Barium-titanate ceramic as an electromechanical transducer," *Bell Lab. Rec.*, vol. 27, pp. 285–289; August, 1949.

Among the crystals that have recently been found to have ferroelectric properties are columbates and tantalates of potassium and sodium. Tungsten trioxide appears to have similar properties.

(553) B. T. Matthias, "New Ferroelectric crystals," *Phys. Rev.*, vol. 75, p. 1771; June 1, 1949.
(554) B. T. Matthias, "Ferro-electric properties of WO_3," *Phys. Rev.*, vol. 76, pp. 430–431; August 1, 1949.

Miscellaneous Applications

Both theoretical and practical papers have appeared on the use of crystals in filters, and also in transducers for ultrasonics. Among other applications described are devices for measuring atmospheric temperature, pressure, and humidity, by observation of changes in resonator frequency or damping; a dynamometer for varia-

(555) E. A. Roberts, and others, "Investigation of use of crystals as meteorologic elements for measurements of temperature, pressure, and humidity," *Quarterly Report No. 3*, December 21, 1948, to March 8, 1949; Armour Research Foundation; *Technical Information Pilot*, p. 964; September 19, 1949.

(556) J. K. Tyson and S. Siegel, "Investigation of use of crystals as meteorologic elements for measurements of temperature, pressure, and humidity," *Quarterly Report No. 1*, Armour Research Foundation, *Technical Information Pilot*, p. 372; December 31, 1948.

(557) J. K. Tyson and S. Siegel, "Investigation of use of crystals as meteorologic elements for measurements of temperature, pressure, and humidity," *Quarterly Report No. 2*, September 9 to December 20, 1948, Armour Research Foundation, *Technical Informaton Pilot* p. 506; March 30, 1949.

(558) W. P. Mason, W. O. Baker, H. J. McSkimin, and J. H. Heiss, "Measurement of shear elasticity and viscosity of liquids at ultrasonic frequencies," *Phys. Rev.*, vol. 75, pp. 936–946; March 15, 1949.

(559) H. T. O'Neil, "Reflection and refraction of plane shear waves in visco-elastic media," *Phys. Rev.*, vol. 75, pp. 928–935; March 15, 1949.

tions in cutting forces; as a means for measuring elastic properties of viscous liquids; and for measuring very small mechanical displacements. Improvements have been recorded in mercury delay lines containing quartz crystals. By taking advantage of the electro-optic effect in ammonium dihydrogen phosphate, high-frequency modulation of a beam of light has been achieved. Finally, piezoelectricity has invaded the field of biology: evidence has been adduced of injurious effects caused by the injection of dusts of piezoelectric crystals in animal tissues.

(560) J. P. Arndt, Jr., "Direct reading microdisplacement meter," *Jour. Acous. Soc. Amer.*, vol. 21, pp. 385–391; July, 1949.

(561) I. L. Auerbach, J. P. Eckert, Jr., R. F. Shaw, and C. B. Sheppard, "Mercury delay line memory using a pulse rate of several megacycles," Proc. I.R.E., vol. 37, pp. 855–861; August, 1949.

(562) G. D. Gotschall, "Light modulation by *p*-type crystals," *Jour. Soc. Mot. Pic. Eng.*, vol. 51, pp. 13–20; July, 1948; Proc. I.R.E., vol. 37, p. 215; February, 1949.

(563) S. M. Evans, "Tissue responses to physical forces. I. The pathogenesis of silicosis. A preliminary report," *Jour. Ind. Hygiene and Toxicology*, vol. 30, pp. 353–357; November, 1948.

(564) S. M. Evans and W. Zeit, "Tissue responses to physical forces II. The response of connective tissue to piezoelectrically active crystals," *Jour. Lab. and Clinical Med.*, vol. 34, pp. 592–609; May, 1949. Also "III. The ability of galvanic current flow to stimulate fibrogenesis," *ibid.*, pp. 592–615.

(565) H. Bommel, "Über die Eignung von Ammoniumphosphatkristallen als Ultraschallgeneratoren," (The utility of ammonium phosphate crystals as ultrasonic generators), *Helv. Phys. Acta*, vol. 21, pp. 403–410; September 30, 1948.

(566) W. G. Cady, "A theory of the crystal transducer for plane waves," *Technical Report No. 2*, Wesleyan University, September 29, 1948; *Jour. Acous. Soc. Amer.*, vol. 21, pp. 65–73; March, 1949.

(567) F. S. Farkas, F. J. Hallenbeck, and F. E. Stehlik, "Band pass filter, band elimination filter and phase stimulating network for carrier program systems," *Bell Sys. Tech. Jour.*, vol. 28, pp. 196–220; April, 1949.

(568) C. F. Floyd and R. L. Corke, "Crystal filters for radio receivers," *Jour. IEE* (London), vol. 94, part 3A, pp. 915–926; 1947.

(569) W. Herzog, "Bandsperren mit Schwingkristallen," (Band filters with vibrating crystals), *A. E. Ü.*, vol. 2, pp. 22–38; 1948.

(570) P. Naslin, "Piezoelectric dynamometer for recording variations in cutting forces," *Rev. Gén. Eléc.*, vol. 57, pp. 361–364; September, 1948; (*Phys. Abstr.*, vol. 52, p. 212; May, 1949.)

(571) B. Sandal, "Variable bandwidth crystal filters," *Radiotronics*, pp. 78–87; September and October, 1948. Also, Proc. I.R.E., vol. 37, p. 967; August, 1949.

(572) P. K. Taylor, "Single-sideband crystal filters," *Electronics*, vol. 21, pp. 116–120; October, 1948.

(573) G. W. Willard, "Focusing ultrasonic radiators," *Jour. Acous. Soc. Amer.*, vol. 21, pp. 360–375; July, 1949.

(574) E. S. Willis, "Crystal filters using ethylene diamine tartrate in place of quartz," *Trans. A.I.E.E.* (*Elec. Eng.*), vol. 67, pp. 552–556; 1948.

Radio Transmitters

The television industry was responsible for the greatest activity despite the fact that no new construction permits were granted in the United States. The number of operating television stations almost doubled during 1949, the number increasing from 51 to 98. Considerable work was done in an effort to improve the quality of the transmitted picture within the bandwidth limitations of the allocated channels.

(575) F. J. Bingley, "Design for the future," *Electronics*, vol. 22, pp. 70–81; September, 1949.

(576) R. D. Kell and G. L. Fredendall, "Standardization of the transient response of television transmitters," *RCA Rev.*, vol. 10, pp. 17–34; March, 1949.

(577) E. D. Goodale and R. C. Kennedy, "Phase and amplitude equalizer for television use," *RCA Rev.*, vol. 10, pp. 35–42; March, 1949.

The likelihood of new television channel allocations in the ultra-high-frequency region stimulated a great deal of interest in the generation of ultra-high-frequency energy.

(578) C. L. Cuccia, "Certain aspects of triode reactance tube performance for frequency modulation at ultra-high frequencies," *RCA Rev.*, vol. 10, pp. 79–98; March, 1949.

(579) G. M. Rose, D. W. Pawer, and W. A. Harris, "Pencil type uhf triodes," *RCA Rev.*, vol. 10, pp. 321–338; September, 1949.

(580) J. S. Donal, Jr. and R. R. Bush, "A spiral-beam method for the amplitude modulation of magnetrons," Proc. I.R.E., vol. 37, pp. 375–382; April, 1949.

(581) R. M. Wilmotte and P. A. DeMars, "Polycast system for TV on uhf," *FM and Telev.*, vol. 8, pp. 26–28, 32, 44–46; December, 1948.

Less activity was noted this year in FM broadcasting than in previous years, with only about 60 new construction permits issued. Some advances were made in FM transmitter design and performance measurement.

(582) D. L. Balthis, "Coaxial 50 kw FM broadcast amplifier," *Electronics*, vol. 22, pp. 68–73; May, 1949.

(583) F. E. Talmage, "FM proof of performance techniques," *Communications*, vol. 29, pp. 22–23, 32; April, 1949.

The relaying of video signals by microwave transmitters was expanded and techniques were improved.

(584) W. Forster, "6000-Mc television relay system," *Electronics*, vol. 22, pp. 80–85; January, 1949.

(585) F. J. Budelman, "Equipment for remote pickup," *FM and Telev.*, vol. 9, pp. 13–16; June, 1949.

The mobile radio field continued its rapid growth both here and abroad. The end of the year saw over 200,000 licensed mobile transmitters in existence in the United States alone. New rules and frequency allocations became effective July 1, 1949, making way for even further expansion.

(586) G. H. Underhill, "New frequency assignments for mobile radio systems," *Elec. Eng.*, vol. 68, pp. 951–955; November, 1949.

(587) W. D. Hailes, "Railroad radio," *Elec. Eng.*, vol. 68, pp. 1–6; January, 1949.

(588) J. Courtney, "New FCC rules mean more mobile radio," *Electronics*, vol. 22, pp. 66–69; August, 1949.

(589) H. Kappler, "The introduction into Switzerland of public telephone service in vehicles," *Bull. Ass. Swisse Elec.*, July 9, 1949.

Coaxial and annular tank circuits were used as a means of obtaining multiple tube operation at high frequencies. Using coaxial type circuits, it was found practical to obtain powers in excess of 50 kw in the FM frequency band and powers of 1 kw at frequencies up to 1,000 Mc.

The construction of 150 new broadcasting stations was planned or completed during the year in the United States, and many stations increased power. Work on low-frequency transmitters was featured by the use of

iron-core interstage and output transformers capable of operating over the frequency range of 100 to 500 kc.

The elimination of tube rectifiers was accomplished by using newly developed high-voltage metallic rectifiers.

(590) I. F. Deise and L. W. Gregory, "3 kw mf transmitter design using iron-core interstage and output transformers," *Communications*, vol. 29, pp. 12–14, 35, October; pp. 12–13, November; pp. 10–11, December, 1949.
(591) N. B. Tharp and C. K. Hooper, "High voltage metallic rectifiers applied to broadcast transmitters," *Communications*, vol. 29, pp. 12–13, 27; September, 1949.

Microwave communications systems employing pulse-time and pulsed-frequency modulation were described.

(592) A. E. Ross, "Theoretical study of pulse-frequency modulation," Proc. I.R.E., vol. 37, pp. 1277–1286; November, 1949.
(593) K. S. Kunz, "Bilinear transformations applied to the tuning of the output network of a transmitter," Proc. I.R.E., vol. 37, pp. 1211–1217; October, 1949.
(594) H. Goldberg and C. C. Bath, "Multiplex employing pulse-time and pulsed-frequency modulation," Proc. I.R.E., vol. 37, pp. 22–28; January, 1949.
(595) A. G. Kandoian and A. M. Levine, "Experimental ultra-high-frequency multiplex broadcasting system," Proc. I.R.E.,vol. 37, pp. 694–701; June, 1949.
(596) W. H. Doherty, "Operation of AM broadcast transmitters into sharply tuned antenna systems," Proc. I.R.E., vol. 37, pp. 729–734; July, 1949.
(597) L. E. Norton, "Broad-band power-measuring methods at microwave frequencies," Proc. I.R.E., vol. 37, pp. 759–766; July, 1949.

Railroad and Vehicular Communications

An outstanding development in the mobile communications field was the issuance of permanent rules for general mobile services by the Federal Communications Commission. The new rules recognized and provided frequency allocations for four major classes of mobile radio service: (1) domestic public land mobile radio services; (2) public safety including police, fire, forestry-conservation, highway maintenance and special emergency radio services; (3) industrial, including power petroleum, forest products, motion pictures, relay press, special industrial and low-power industrial services; and (4) land transportation including intercity bus, highway truck, railroad, taxicab, urban transit and automobile emergency services.

(598) "Title 47—Telecommunication," *Federal Register*, vol. 14, pp. 2264–2358; May 6, 1949.

Service expansion in diversified fields of application continued throughout the year. The expansion was marked more by growth in existing fields of application than by new applications. Several applications in other countries were noted.

(599) "Radio on 347 Miles of the Erie," *Ry. Signaling*, vol. 41, pp. 754–760; December, 1948.
(600) W. R. Triem, "Communication services and improvements on the Pennsylvania Railroad," *Tel. and Tel. Age*, vol. 66, pp. 7–9, 30; December, 1948.
(601) R. H. Herrick, "Great Lakes radiotelephone system," *Elec. Eng.*, vol. 68, pp. 152–157; February, 1949.
(602) R. E. Kolo, "Telephone Company mobile radiotelephone for power utility use," *Edison Elec. Inst. Bull.*, vol. 17, pp. 73–74, 82; March, 1949.
(603) "Radio-Telephony at Whitemoor marshalling yard," *Engineer*, vol. 187, pp. 326–327; March 25, 1949.
(604) "Communications," *Ry. Age*, vol. 126, pp. 1052–1053; May 21, 1949.
(605) F. J. Corporon, "New space radio relay system," *Ry. Signaling*, vol. 42, pp. 374–377; June, 1949.
(606) "Installation of two-way space radio equipment on the Rio Grande in Denver, Colo.," *Ry. Signaling and Commun.*, vol. 42, pp. 438–441; July, 1949.
(607) "Modern communication in train and yard service," *Ry. Signaling and Commun.*, vol. 42, pp. 442–444; 446; July, 1949.
(608) S. W. Miller, "Radio communication on the nickel plate," *Tel. and Tel. Age*, vol. 67, pp. 6–7; August, 1949.
(609) R. W. Goss, "South Australian police FM network," *Communications*, vol. 29, pp. 14–16; September, 1949.

Equipment developments during the year were directed toward reduction in size, reduction of power consumption, and reduction of interference. There were a number of new antennas developed specifically for mobile radio applications.

(610) A. A. Curry, "Mobile FM equipment design for railroads," *Tele-Tech.*, vol. 7, pp. 40–43; December, 1948.
(611) R. G. Rowe, "Collinear coaxial array for 152 megacycles," *Tele-Tech.*, vol. 8, pp. 34–35, 60; January, 1949.
(612) D. H. Hughes, "Vhf radio equipment for mobile services," *British IRE Jour.*, vol. 9, pp. 30–44; January, 1949.
(613) J. K. Kulanski, "Pushbutton selective calling," *Electronics*, vol. 22, pp. 92–96; February, 1949.
(614) J. S. Brown and V. J. Moffatt, "Directional antenna for the 152–162 megacycle communications band," *Communications*, vol. 29, pp. 14–16, 35; March, 1949.
(615) D. R. Rhodes, "Flush-mounted antenna for mobile application," *Electronics*, vol. 22, pp. 115–117; March, 1949.
(616) R. A. Ratcliffe and R. S. Zucker, "Mobile FM communications equipment for Australian conditions," *Proc. IRE* (Australia), vol. 10, pp. 101–113; April, 1949.
(617) D. E. Noble, "Adjacent-channel operation of mobile equipment," *Electronics*, vol. 22, pp. 90–95; June, 1949.
(618) W. C. Babcock, "Mobile radio antennas for railroads," *Tel. and Tel. Age*, vol. 67, pp. 8, 10, 27; July, 1949.
(619) H. Magnuski, "Cavity resonators in mobile communications," *Communications*, vol. 29, pp. 8–11; August, 1949.
(620) M. R. Winkler, "Instantaneous deviation control," *Electronics*, vol. 22, pp. 97–99; September, 1949.

The following papers of general interest in the mobile radio field were published.

(621) E. Toth, "AM and narrow band FM vhf communications," *Electronics*, vol. 22, pp. 84–91; February, 1949. Also, *Electronics*, vol. 22, pp. 102–108; March, 1949.
(622) D. K. Gannett and W. R. Young, "Ratio of frequency swing to phase swing in phase and frequency modulation systems transmitting speech," Proc. I.R.E., vol. 37, pp. 258–263; March, 1949.

Receivers

Television Receivers

To reduce interference from local oscillator radiation, the intermediate frequency was raised to almost double its former value. Intercarrier sound systems became increasingly popular. Built-in antenna systems were introduced, provision being made in some cases for tuning of the antenna by the user. Transformerless models and even ac/dc designs were described, one of the latter being of the tuned radio-frequency type. Increasing emphasis was placed on obtaining better sound fidelity from television receivers. Receivers capable of providing pictures in color in accordance with several basically different systems of transmission were operated experimentally and demonstrated to the FCC.

(623) R. R. Batcher, "Trends in television and radio receiver design," *Tele-Tech.*, vol. 8, pp. 22–24, 52; January, 1949.
(624) D. D. Cole, "Video receiver circuits simplified," *Tele-Tech.*, vol. 8, p. 33; January, 1949.

(625) W. Stroh, "An intercarrier sound system for television receivers using the 6BN6," presented, Radio Fall Meeting, Syracuse, N. Y., November 1, 1949.
(626) R. B. Albright, "A tunable built-in TV antenna," *Electronics*, vol. 22, pp. 134, 136, 140, 144, 146 and 150; November, 1949.
(627) W. H. Buchsbaum, "Designing a TRF television receiver," *Tele-Tech*, vol. 8, pp. 36–39; August, 1949.
(628) C. G. McProud, "Improved audio quality from standard TV receiver," *Audio Eng.*, vol. 33, pp. 28, 30; October, 1949.
(629) J. H. Battison, "Color television transmission systems," *Tele-Tech*, vol. 8, pp. 18–20, 52; October, 1949.
(630) E. W. Engstrom, "How RCA's color TV works," *FM and Telev.*, vol. 9, pp. 11–13, 15, 30; October, 1949.

Particular attention was given to improving the front-end design of television receivers. Several different arrangements in current use were noted. In some instances, separate amplifiers were provided for the high and low television bands. Synchronization methods were improved to reduce the detrimental effect of noise. Smaller components, such as deflection yokes, also received attention. Special attention was given to the problem of improving horizontal deflection circuits to reduce power consumption and heating.

(631) J. A. Hansen, "Simplified TV receiver channel switching mechanism," *Tele-Tech*, vol. 7, pp. 36–38, 72; December, 1948.
(632) J. O. Silvey, "A front end for television receivers," *Tele-Tech*, vol. 8, pp. 36–37, 54–55; January, 1949.
(633) D. E. Foster, "Antenna input systems for television receivers," *Tele-Tech*, vol. 8, pp. 28–30, 56; February, 1949.
(634) F. R. Norton, "Oscillator and mixer circuits for TV receivers," *Tele-Tech*, vol. 8, pp. 31, 42–43; February, 1949.
(635) H. M. Watts, "Television front-end design," *Electronics*, vol. 22, pt. I, pp. 92–97, April, 1949; pt. II, pp. 106–110, May, 1949.
(636) K. Schlesinger, "Locked oscillator for television synchronization," *Electronics*, vol. 22, pp. 112–117; January, 1949.
(637) E. L. Clark, "Automatic frequency phase control of television sweep circuits," Proc. I.R.E., vol. 37, pp. 497–500; May, 1949.
(638) A. Easton, "Stagger-peaked video amplifiers," *Electronics*, vol. 22, pp. 118–120; February, 1949.
(639) A. B. Bereskin, "Cathode-compensated video amplification," *Electronics*, vol. 22, pt. I, pp. 98–103, June, 1949; pt. II, pp. 104–107, July, 1949.
(640) J. M. Miller, Jr., "Cathode neutralization of video amplifiers," Proc. I.R.E., vol. 37, pp. 1070–1073; September, 1949.
(641) R. C. Palmer and L. Mantner, "A new figure of merit for the transient response of video amplifiers," Proc. I.R.E., vol. 37, pp. 1073–1077; September, 1949.
(642) K. Schlesinger, "Anastigmatic yoke for picture tubes," *Electronics*, vol. 22, pp. 102–107; October, 1949.
(643) O. H. Schade, "Characteristics of high-efficiency deflection and high-voltage supply systems for kinescopes," presented, Radio Fall Meeting, Syracuse, N. Y., November 1, 1949.

The proposal by the Federal Communications Commission that frequencies in the band 475 to 890 Mc be utilized for television broadcasting resulted in the development of converters to permit an ordinary television receiver to receive such broadcasts. The proposal also caused a re-examination of the choice of the optimum intermediate frequency for a receiver capable of covering both the new band and the old vhf bands.

(644) R. P. Wakeman, "Continuously tuned converter for uhf television," *Electronics*, vol. 22, pp. 68–71; July, 1949.
(645) J. D. Reid, "The influence of uhf allocations on receiver design," Proc. I.R.E., vol. 37, pp. 1179–1181; October, 1949.

Radio Receivers

As in the past with AM receivers, it was found possible to reduce still further the cost of FM receivers by using an ac/dc arrangement. Improved receivers of this type were described. Special-purpose fixed-frequency FM receivers, both with and without supersonic control for varying the output level from the transmitter, were developed. Although both ratio detectors and limiter-discriminator combinations continued to be widely used, a new arrangement requiring a special tube was proposed.

(646) E. C. Freeland, "FM receiver design problems," *Electronics*, vol. 22, pp. 104–110; January, 1949.
(647) G. E. Gustafson, "Low-cost receivers can give genuine FM performance," *FM and Telev.*, vol. 9, pp. 13–14, 34; April, 1949.
(648) F. A. Spindell, "Fixed-frequency FM tuners," *FM and Telev.*, vol. 9, pp. 16–17, 32; April, 1949.
(649) L. J. Giacoletto, "Experimental tube for FM detection," *Electronics*, vol. 22, pp. 87–89; November, 1949.

Further theoretical work was done on super-regenerative receivers, and on the evaluation of the performance of receiver input circuits and linear detectors. An increasing tendency to utilize crystal detectors, particularly germanium diodes, was noted, and a new type of crystal receiver for local broadcasts was described.

(650) G. V. Eltgroth, "An examination of performance capabilities of supreregenerative receivers," *Tele-Tech*, vol. 8, pt. I, pp. 24–27, 57, February, 1949; pt. II, pp. 40–43, 71, March, 1949.
(651) H. A. Glucksman, "Superregeneration—an analysis of the linear mode," Proc. I.R.E., vol. 37, pp. 500–504; May, 1949.
(652) P. G. Sulzer, "Noise figures for receiver input circuits," *Tele-Tech*, vol. 8, pp. 40–42, 57; May, 1949.
(653) R. H. De Lano, "Signal-to-noise ratios of linear detectors," Proc. I.R.E., vol. 37, pp. 1120–1126; October, 1949.

Research

Work on subjects of basic and applied research has covered entirely the ever-expanding electronics field. Contributions have been widespread, coming from research workers in the academic field, from government laboratories, and from the various industry laboratories.

In addition to reporting the end results of research, a considerable amount of thought and discussion was directed to management of and facilities for research.

(654) R. D. Bennett, "Research management for the government," *Proc. NEC*, vol. 5; 1949.
(655) H. A. Leedy, "Research management for the research foundation," *Proc. NEC*, vol. 5; 1949.
(656) F. A. Rohrman, "Research management for the universities," *Proc. NEC*, vol. 5; 1949.
(657) D. E. Chambers, "Research management for industry," *Proc. NEC*, vol. 5; 1949.
(658) R. B. Dittmar, "The development of physical facilities for research," Proc. I.R.E., vol. 37, pp. 423–426; April, 1949.
(659) C. E. Barthel, Jr., "Personnel administration in research and development organizations," Proc. I.R.E., vol. 37, pp. 426–429; April, 1949.
(660) A. H. Schooley, "Information exchange as a management tool in a large research organization," Proc. I.R.E., vol. 37, pp. 429–432; April, 1949.

Sound Recording and Reproducing

Disk Recording and Reproduction

The fine groove long-playing record for the home market created a demand for reproducing equipment and many manufacturers are producing special pickups and turntables. Several new reproducers were announced, one utilizing the variation in electrode spacing of an electron tube and the other a new ceramic material having piezoelectric properties.

Increased fidelity and reduction of distortion were discussed in several papers. Flutter and wow measurements continued to receive attention, particularly the

evaluation of the subjective effects of wow and flutter; tracing distortion was also treated.

(661) H. Davies, "Design of high fidelity disk recording equipment," *Jour. IEE* (London), vol. 95, part 3, pp. 467–470, November, 1948.
(662) H. E. Roys and M. S. Corrington, "Tracing distortion in phonograph recording," *RCA Rev.*, vol. 10, pp. 241–253; June, 1949.
(663) S. J. Begun, "Limitation of sound recording," *Communication*, vol. 29, pp. 28–29; August, 1949.
(664) N. C. Pickering, "Misconception about record wear," *Audio Eng.*, vol. 32, pp. 11–14; June, 1948.
(665) L. S. Goodfriend, "Subjective testing of sound recording equipment," *Jour. Acous. Soc. Amer.*, vol. 21, pp. 81–84; March, 1949.
(666) M. J. L. Pulling, "Sound recording as applied to broadcasting," *BBC Quarterly*, vol. 3, pp. 108–111; July, 1948.
(667) R. G. Peter, "Broadcast transcription reproducting system maintenance," *Communications*, vol. 28, pp. 26; October, 1948.
(668) L. G. Hector, "Ceramic phono pickups," *Electronics*, vol. 21, pp. 94–96; December, 1948.
(669) H. F. Olsen and J. Preston, "Electron tube phonograph pickup," *Audio Eng.*, vol. 32, pp. 17–20; August, 1948.

Radio Phonographs

Improved record changers, some of which are capable of operating at three different turntable speeds and with records of several different diameters, were developed and supplied with many radio-phonograph combinations, to cope with the multiplicity of record types offered during the year. In some cases, a separate changer was provided for 45-rpm records. Ingenious circuits were devised for improving the performance of inexpensive pickups, some of these circuits utilizing feedback arrangements.

(670) B. R. Carson, A. D. Burt, and H. I. Reiskind, "A record changer and record of complementary design," *RCA Rev.*, vol. 10, pp. 173–190; June, 1949.
(671) P. C. Goldmark, R. Snepvangers, and W. S. Bachman, "The Columbia long-playing microgroove recording system," Proc. I.R.E., vol. 37, pp. 923–927; August, 1949.
(672) E. J. O'Brien, "High-fidelity response from phonograph pickups," *Electronics*, vol. 22, pp. 118–120; March, 1949.

Magnetic Recording and Reproduction

The stringent demands of broadcasting, motion pictures, and recording studios for high-quality reproduction led to extensive study of magnetic recording media. Spurious printing, correct bias, noise, and distortion were discussed in the literature; several articles for operating personnel have appeared, which discussed the relation between correct bias and operating level consistent with minimum distortion. Several editing machines for magnetic tape recorders were introduced. Stereophonic magnetic recordings were demonstrated. The duplication of magnetic recordings received much attention and an interesting method of direct printing of magnetic recording was introduced.

The synchronism of magnetic playback system to existing motion picture projection was introduced; one method employed a stroboscopic comparison between marks printed on the magnetic tape and the flicker produced on the motion picture screen, another uses a phase comparison between a tone simultaneously recorded with the program material and the driving source which also supplies the synchronous motor of the projector.

Nearly all major motion picture studios experimented with, or were actually using, magnetic recording for many of their recording requirements.

(673) J. G. Frayne and H. Wolfe, "Magnetic recording in motion picture techniques," *Jour. Soc. Mot. Pic. Eng.*, vol. 53, pp. 217–234; September, 1949.
(674) E. Masterson, "35 mm magnetic sound," *Jour. Soc. Mot. Pic., Eng.*, vol. 51, pp. 481–488; November, 1948.
(675) J. W. Gratian, "Noise in magnetic recording systems as influenced by the characteristics of bias and erase signals," *Jour. Acous. Soc. Amer.*, vol. 21, pp. 74–81; March, 1949.
(676) G. L. Dimmick and S. W. Johnson, "Optimum high-frequency bias in magnetic recording," *Jour. Soc. Mot. Pic. Eng.*, vol. 51, pp. 489–499; November, 1948.
(677) R. Marchant, "Tape characteristics for audio quality," *Tele-Tech*, vol. 8, pp. 30–34; July, 1949.
(678) D. O'Dea, "Magnetic recording for the technical man," *Jour. Soc. Mot. Pic. Eng.*, vol. 51, pp. 468–480; November, 1948.
(679) S. W. Johnson, "Factors affecting spurious printing," *Jour. Soc. Mot. Pic. Eng.*, vol. 52, pp. 619–628; June, 1949.
(680) L. C. Holmes, "An evaluation of new and old techniques to improvements of the magnetic recording system," *Proc. NEC*, vol. 4; 1948.
(681) M. Camras, "A stereophonic magnetic recorder," Proc. I.R.E., vol. 37, pp. 442–447; April, 1949.
(682) R. S. O'Brien, "Edispot, tape editor," *Audio Eng.*, vol. 32, pp. 11–13; July, 1948.
(683) S. J. Begun, "Magnetic Recording," Murray Hill Books, Inc., New York, N. Y.; 1949.

Symbols

The ASA published during 1949 the following standards concerning symbols:

(684) Z10.5—1949; Letter Symbols for Electrical Quantities.
(685) Z10.6—1948; Letter Symbols for Physics.
(686) Z32.10—1948; Graphical Symbols for Electron Devices.

The Munitions Board Standards Agency published during 1949 the JAN-STD-15—1948 National Military Establishment *Standard for Electrical and Electronic Symbols*, of interest to manufacturers selling electrical equipment to the Armed Services.

Television Systems

Developments in Color Television

Work on three television color systems progressed during the year, including demonstrations by RCA of their dot-sequential system, by CBS of a field-sequential system, and by Color Television, Inc., of a line-sequential system.

(687) "Interlaced-dot color television announced by RCA," *Electronics*, vol. 22, p. 122; November, 1949.
(688) Boothroyd and Wilson, "Dot systems of color television, Part I," *Electronics*, vol. 22, p. 88; December, 1949.
(689) D. G. Fink, "New directions in color television," *Electronics*, vol. 22, p. 66; December, 1949.

Over-all System Characteristics

Additional work was reported on phase and amplitude characteristics of commercial television transmitters. Equipment was described which can equalize or correct for transient distortion caused by the transmitter vestigial-sideband filter and the 4.5-megacycle cutoff of the average receiver. General use of this type of equalization is expected to offer considerable system improvement.

(690) R. D. Kell and G. L. Frendendall, "Standardization of the transient response of television transmitters," *RCA Rev.*, vol. 10, pp. 17–34; March, 1949.
(691) E. D. Goodale and R. C. Kennedy, "Phase and amplitude equalizer for television use," *RCA Rev.*, vol. 10, pp. 35–42; March, 1949.

Video Techniques and Television

Television broadcasting activity continued to grow rapidly despite the continuation of the "freeze" by the Federal Communications Commission on applications for new construction permits. To resolve the problem of filling the need for new television stations in the best interest of the public, the Federal Communications Commission opened a hearing in September that promised to last, with some intermissions, well into 1950.

(692) "JTAC requests technical co-operation in connection with FCC television hearings," Proc. I.R.E., vol. 36, pp. 1515–1517; December, 1948.
(693) R. Lewis, "The Ad Hoc Committee Report," *Communications*, vol. 29, pp. 6–9; July, 1949.
(694) "Television and the FCC vs. tropospheric interference," *Tele-Tech*, vol. 8, pp. 68–69; March, 1949.
(695) "FCC's plans for future of TV," *Tele-Tech*, vol. 8, pp. 52–53; July, 1949.
(696) "DuMont's TV allocation plan," *Tele-Tech*, vol. 8, p. 41; October, 1949.
(697) R. M. Wilmotte and P. A. DeMars, "Polycast system for TV on uhf," *FM-Telev.*, vol. 8, pp. 26–28; December, 1948.
(698) W. Coy, "FCC plans for TV expansion," *FM-Telev.*, vol. 9, p. 22; May, 1949.
(699) M. B. Sleeper, "Nationwide TV service," *FM-Telev.*, vol. 9, pp. 10–19; August, 1949.

The three major questions were:

(1) Interstation interference among present commercial very-high-frequency channels due largely to unexpected tropospheric propagation.

(2) The opening of some ultra-high-frequency channels to commercial television broadcasting to accommodate present needs.

(3) The role that color television is to play.

Color television aroused some of the most heated discussions in the hearing. It centered around three basic proposed systems: field-sequential, line-sequential, and dot-sequential transmission of the three primary colors. In addition, several demonstrations were made of the field sequential system for educational purposes in the medical field.

Emphasis was laid on five factors relative to proposed color television systems: (a) compatability with present standard receivers or ability to receive the color transmission in black and white with little or no modifications to existing sets; (b) ease of conversion of existing sets to display color; (c) cost of new color receivers; (d) the degree to which the system had been field tested; and (e) the quality of the color system both present and potential.

(700) J. H. Battison, "Color television transmission systems," *Tele-Tech*, vol. 8, pp. 18–20; October, 1949.
(701) "Report on FCC color TV demonstrations at Washington," *Tele-Tech*, vol. 8, pp. 24–27, (cont'd.); November, 1949.
(702) W. H. Cherry, "Colorimetry in television," *Jour. Soc. Mot. Pic. Eng.*, vol. 51, pp. 613–642; December, 1948.

Experiments to see what could be done to ease the severity of the effects of co-channel interference were carried on by industry through the use of offset carriers (intentionally 10 kilocycles displaced from the assigned frequency) in lieu of synchronized carriers proposed earlier. Some 15 decibels of improvement appeared realizable with either system. The advantage of the newer system is that the intermediate station equipment and connections are eliminated.

(703) A. Francis, "Synchronization of TV carriers to reduce co-channel interference," *Tele-Tech*, vol. 8, p. 29; January, 1949.

In addition, the Federal Communications Commission laboratories demonstrated simulated transmission and interference using FM for the visual system to explore its potential in the ultra-high-frequency band. The results were interesting but not conclusive.

Actual field transmission in the ultra-high- and very-high-frequency ranges were carried out to study comparative propagation effects. The tests showed the advantage of the lower very-high-frequency channels over the upper with respect to received signal strength, and the practicality of ultra-high-frequency transmission.

(704) T. T. Goldsmith, Jr., R. P. Wakeman, and J. D. O'Neil, "A field survey of television Channel 5 propagation of New York metropolitan area," Proc. I.R.E., vol. 37, pp. 556–563; May, 1949.
(705) G. H. Brown, "Field test of ultra-high-frequency television in Washington area," *RCA Rev.*, vol. 9, pp. 565–584; December, 1948.
(706) E. W. Allen, Jr., "Uhf propagation characteristics," *Electronics*, vol. 22, pp. 86–89; August, 1949.
(707) J. Fisher, "Field test of uhf television," *Electronics*, vol. 22, pp. 106–111; September, 1949.
(708) T. T. Goldsmith, Jr., "Progress on uhf television," *FM-Telev.*, vol. 9, pp. 24–26; May, 1949.

To produce television programs the following three techniques were in use:

(1) Direct connections through the rapidly expanding intercity channel facilities of the telephone companies. Some 8,500 channel miles of interconnecting television service were available by the year's end serving twenty-nine communities. The network extended along the eastern seaboard north to Boston, and south to Richmond. It linked the east with the middle west along the northern section of the United States reaching northwest to Madison, Wisconsin, and southwest to St. Louis.

(709) R. Hertzberg, "Coaxial cable joins East & Mid-West TV networks," *Tele-Tech*, vol. 8, pp. 18–20; February, 1949.
(710) G. N. Thayer, A. A. Raetken, R. W. Friis, and A. L. Durkee, "A broadband microwave relay system between New York and Boston," Proc. I.R.E., vol. 37, pp. 183–188; February, 1949.

(2) Delayed transmission through the use of film most of which were taken as "video recordings" of primary transmission, but others as specially recorded scenes and still others as reprojections of old film. The art of taking and projecting these films improved markedly as the year progressed.

(711) G. H. Gordon, "Video recording technics," *Tele-Tech*, vol. 8, pp. 31–33, May, 1949; and pp. 29–31, June, 1949.
(712) J. A. Maurer, "16-mm film suitable for TV," *FM-Telev.*, vol. 9, pp. 20–21; January, 1949.

(713) "Films in television," *Jour. Soc. Mot. Pic. Eng.*, vol. 52, pp. 363–379; April, 1949.

(3) A "spur" connection to an existing transmission through an off-the-air pickup receiver and, in most cases, one or more privately owned microwave relays.

(714) W. McCord, "Simplified handling of television remotes," *Tele-Tech*, vol. 8, pp. 26–31; June, 1949.
(715) E. Labin, "Wide-band television transmission system," *Electronics*, vol. 22, pp. 86–89; May, 1949.
(716) E. H. Schreiber, "Video distribution facilities for television transmission," *Jour. Soc. Mot. Pic. Eng.*, vol. 51, pp. 574–585; December, 1948.

In the field of standardization the IRE Video Techniques Committee proposed definitions and methods of measurement which have been adopted and are being made available to the industry. Of particular concern have been those factors where lack of standardization has created considerable confusion and handicaps in the interconnection of video facilities such as measurement of levels, picture resolution and wave shapes.

A major effort along technical lines to improve the quality of picture reproduction and transmission was evident. In particular, emphasis was laid on techniques for measuring and specifying response.

(717) P. M. Seal, "Square-wave analysis of compensated amplifiers," Proc. I.R.E., vol. 37, pp. 48–58; January, 1949.
(718) W. J. Kessler, "Transient-response equalization through steady-state methods," Proc. I.R.E, vol. 37, pp. 447–450; April, 1949.
(719) M. Nadler, "The synthesis of electric networks according to prescribed transient conditions," Proc. I.R.E., vol. 37, pp. 627–630; June, 1949.
(720) P. R. Aigrain, "Design of optimum transient response amplifiers," Proc. I.R.E., vol. 37, pp. 873–879; August, 1949.
(721) R. C. Palmer and L. Mautner, "A new figure of merit for the transient response of video amplifiers," Proc. I.R.E., vol. 37, pp. 1073–1077; September, 1949.
(722) T. Murakami and M. S. Corrington, "Relation between amplitude and phase in electrical networks," *RCA Rev.*, vol. 9, pp. 602–631; December, 1948.
(723) R. D. Kell and G. L. Fredendall, "Standardization of the transient response of television transmitters," *RCA Rev.*, vol. 10, pp. 17–34; March, 1949.
(724) M. S. Corrington, "Transient response of filters," *RCA Rev.*, vol. 10, pp. 397–429; September, 1949.
(725) D. A. Alsberg and D. Leed, "A precise direct reading phase and transmission measuring system for video frequencies," *Bell Sys. Tech. Jour.*, vol. 28, pp. 221–238; April, 1949.

In addition, gray-scale rendition came in for a great deal of study although there still appear to be many uncontrolled factors. This is particularly true where the intermediate use of film cascades the number of points where fidelity can be lost. Added to the many electronic circuits where distortion may occur are six operations that potentiality introduce errors: (1) studio camera-tube response to incident light; (2) kinescope light output from an electrical signal; (3) film-emulsion response to light; (4) film processing, including printing; (5) television-film camera-tube response to light from projector; and (6) receiver kinescope response to electrical signal.

(726) O. H. Schade, "Electro-optical characteristics of television systems; Part 4—Correlation and evaluation of electro-optical characteristics of imaging systems," *RCA Rev.*, vol. 9, pp. 653–686; December, 1948.
(727) R. E. Blount, "Lighting requirements of television studios," *Tele-Tech*, vol. 8, pp. 24–25; May, 1949.
(728) H. M. Gurin, "Illumination for television studios," *Tele-Tech*, vol. 8, Part 1, pp. 54–56; September, 1949; Part 2, pp. 34–36; October, 1949.

The installation of television transmitters in the present very-high-frequency bands has become commonplace enough to be routine in nature. In the ultra-high-frequency bands, however, tubes and techniques were still reaching into the unknown, both in circuits and tubes.

(729) R. R. Law, W. B. Whalley, and R. P. Stone, "Developmental television transmitter for 500–900 megacycles," *RCA Rev.*, vol. 9, pp. 643–652; December, 1948.
(730) G. H. Brown, W. C. Morrison, W. L. Behrend, and J. G. Reddeck, "Method of multiple operation of transmitting tubes particularly adapted for television transmission with ultra-high-frequency band," *RCA Rev.*, vol. 10, pp. 161–172; June 1949.

The motion picture industry has embarked on a program with two systems: (1) using the standard theater projectors with film which has been exposed by video recording techniques and processes quickly for immediate projection and (2) direct projection of the television image on to the screen by means of highly efficient optics with special kinescopes.

(731) "Theater television," *Jour. Soc. Mot. Pic. Eng.*, vol. 52, pp. 243–267; March, 1949.
(732) R. Hodgson, "Theater television system," *Jour. Soc. Mot. Pic. Eng.*, vol. 52, pp. 540–548; May, 1949.
(733) R. Wilcox and H. J. Schlafly, "Demonstration of large-screen television at Philadelphia," *Jour. Soc. Mot. Pic. Eng.*, vol. 52, pp. 549–560; May, 1949.
(734) B. Kreuzer, "Progress report—theater television," *Jour. Soc. Mot. Pic. Eng.*, vol. 53, pp. 128–136; August, 1949.
(735) J. E. McCoy and H. P. Warner, "Theater television today," *Jour. Soc. Mot. Pic. Eng.*, vol. 53, pp. 321–350; October, 1949.
(736) "Statement on theater television," *Jour. Soc. Mot. Pic. Eng.*, vol. 53, pp. 354–362; October, 1949.

Also proposed is a system of interconnection of theaters in a given area by means of privately owned microwave relays. The Federal Communications Commission was asked for assignment of the necessary channels.

(737) "FCC allocations of frequencies for theater television," *Jour. Soc. Mot. Pic. Eng.*, vol. 53, pp. 351–353; October, 1949.

Wave Propagation

Tropospheric Propagation

Very-high-frequency and microwave field intensities are far stronger well beyond the horizon than can be accounted for by conventional theory. Possibly, scattering of radio waves from atmospheric turbulences may be responsible for this.

Books. Perhaps 1949 may be said to mark the coming of age of the subject of tropospheric propagation of radio waves, in that the first book written by a single author was published.

(738) H. Bremmer, "Terrestrial Radio Waves," Elsevier Publishing Co., New York, N. Y.; 1949.

Mathematical Theory. Another contribution to the controversy over the surface wave of Sommerfeld appeared in English and in French. A difficulty in Sommerfeld's argument was uncovered, and the final results were found to be in accord with Weyl's solution and Burrows' experimental findings.

A treatment by Sommerfeld himself became available in English.

(739) T. Kahan and G. Eckart, "On the electromagnetic surface wave of Sommerfeld," *Phys. Rev.*, vol. 76, pp. 406–410; August 1, 1949.
(740) T. Kahan and G. Eckart, "Propagation of electromagnetic waves above the ground. Solution of the problem of the surface wave," *Jour. Phys. Radium*, vol. 10, pp. 165–176; May, 1949.
(741) A. Sommerfeld, "Partial Differential Equations in Physics," Academic Press Inc., New York, N. Y.; chap. 6.
(742) B. A. Vvedenski, "Work of the Soviet scientists in the field of propagation of ultra-short radio waves," *Bull. Acad. Sci.* (USSR), pp. 835–854; June, 1948 (In Russian).
(743) V. A. Fock, "Propagation of a direct wave around the earth, taking into account diffraction and refraction," *Bull. Acad. Sci.* (USSR), vol. 12, pp. 81–97; March–April, 1948 (In Russian). English abstract, PROC. I.R.E., vol. 37, p. 108; January, 1949.
(744) O. E. H. Rydbeck, "On the propagation of waves in an inhomogeneous medium," *Trans. of the Chalmers University of Technology*, Gothenberg, Sweden, no. 74, 35 pp.; 1948 (In English).
(745) W. Pfister, "Theorie der Wellenausbreitung Langs der Erde, Einschliesslich Des Einflusses Der Trøposphäre," FIAT Review of German Science, 1936–1946; Electronics II, pp. 127–133.
(746) J. S. McPetrie, B. Starnecki, H. Jarkowski, and L. Sicinski, "Oversea propagation on wavelengths of 3 and 9 centimeters," PROC. I.R.E., vol. 37, pp. 243–257; March, 1949.
(747) F. J. Kerr, "Radio superrefraction in the coastal regions of Australia," *Aust. Jour. Sci. Res.*, ser. A, vol. 1, pp. 443–463; December, 1948.
(748) M. D. Rocco and J. B. Smyth, "Diffraction of high-frequency radio waves around the earth," PROC. I.R.E., vol. 37, pp. 1195–1203; October, 1949.
(749) A. W. Straiton, "Microwave phase front measurements for overwater paths of 12 and 32 miles," PROC. I.R.E., vol. 37, pp. 808–813; July, 1949.
(750) T. T. Goldsmith, R. P. Wakeman, and J. D. O'Neill, "A field survey of television channel 5 propagation of New York Metropolitan Area," PROC. I.R.E., vol. 37, pp. 556–568; May, 1949.
(751) E. W. Allen, Jr., "Uhf propagation characteristics," *Electronics*, vol. 22, pp. 86–89; August, 1949.
(752) H. R. Gracely, "Temperature variations of ground wave signal intensity at standard broadcast frequencies," PROC. I.R.E, vol. 37, pp. 360–363; April, 1949.
(753) G. W. Pickard and H. T. Stetson, "Tropospheric effects in ionosphere-supported radio transmission," PROC. I.R.E., vol. 37, pp. 596–599; June, 1949.

Propagation Experiments. An elaborate microwave propagation experiment was that performed during 1943–1946 across Cardigan Bay. A detailed analysis of five months of data on wavelengths of 3 and 9 centimeters was published, along with conclusions drawn from the entire experiment.

Observational material on propagation from very-high-frequency coastal radars in Australia was summarized.

The first results from the Navy Electronic Laboratory's experimental station in Arizona were published. The measured height-gain relations in the lowest 200 feet over a 47-mile desert path were compared with theory for frequencies between 25 and 9,000 megacycles, both for standard and non-standard meteorological conditions. The outstanding anomaly was much stronger than standard field intensities observed for low antennas at microwave frequencies even under standard or substandard meteorological conditions.

At the University of Texas, both relative phase and signal strength have been measured as a function of antenna height above sea. The most puzzling discrepancy was the different shapes of the height-gain curves depending on whether the transmitting or receiving antenna was moved.

Rather unusual types of propagation measurements are described in connection with determining the service areas of television and frequency-modulation broadcast stations in urban areas, where terrain roughness becomes a dominant factor.

Some of the estimates used by the Federal Communications Commission for time and space variations of tropospheric field intensities at very- and ultra-high frequencies have been published.

Almost all work on tropospheric propagation has been at frequencies higher than those affected by the ionosphere. In 1949, however, several papers appeared that indicate statistically that the troposphere does affect field intensities in the broadcast and high-frequency bands, even though such effects are usually masked by larger ionosphere-caused changes.

Angle of Arrival. A new approach was made in determining accurately the angle of arrival of microwaves over a smooth surface. The method involved the relative signal strengths and phases in three vertically spaced antennas.

The first comprehensive discussion of site errors in very-high-frequency direction finders was published.

(754) E. W. Hamlin, P. A. Seay, and W. E. Gordon, "A new solution to the problem of vertical angle-of-arrival of radio waves," *Jour. Appl. Phys.*, vol. 20, pp. 248–251; March, 1949.
(755) H. G. Hopkins and F. Horner, "Direction-finding site errors at very-high frequencies." *Jour. IEE* (London), vol. 96, part 3, pp. 321–332; July, 1949.

Radio Meteorology

Ever since variable atmospheric refraction was recognized, it has been hoped that purely meteorological measurements and theory might explain, and even predict, the index-of-refraction profiles in the atmosphere that affect field intensities. A review of this problem was published.

Further meteorological analysis was made of the low-level soundings made at Radiation Laboratory in 1944.

Eddy diffusion in the lower atmosphere was treated in a recent monograph.

The original attempt to predict radio-field intensities from meteorological measurements proved more difficult than had been anticipated, and now the reverse was tried, that is, deduction of the refractive-index profiles from radio measurements made over a path. MacFarlane enunciated the method and Straiton extended the idea by using phase-versus-height as well as signal strength-versus-height radio measurements to deduce the refractive-index profiles and to compare the attenuations deduced from the profiles with those actually measured.

(756) H. G. Booker, "Some problems in radio meteorology," *Quart. Jour. Roy. Met. Soc.*, vol. 74, pp. 277–315; July–October, 1948.
(757) R. A. Craig, "Vertical eddy transfer of heat and water vapor in stable air," *Jour. Met.*, vol. 6, pp. 123–133; April, 1949.
(758) O. G. Sutton, "Atmospheric Turbulence," Methuen, 1949.

(759) A. W. Straiton, "An extension of MacFarlane's method of deducing refractive index from radio observations," *Jour. Appl. Phys.*, vol. 20, p. 228; February, 1949.

Meteorological Echoes and Scattering. Some short-range echoes obtained from an otherwise clear atmosphere on suitable microwave radars, appear almost certain to be caused by insects, and not by atmospheric discontinuities.

A comprehensive summary of some observations on reflection of radio signals from the troposphere was published.

Atmospheric turbulence has been proposed as a possible cause of observed tropospheric fields beyond the horizon far in excess of what can be accounted for on conventional theory. Booker and Gordon presented a paper on "Radio scattering in the troposphere" at a symposium at the Navy Electronics Laboratory, San Diego, Calif., in July, 1949, which appears on pp. 401–412 of this issue of PROCEEDINGS. A Russian paper has appeared on the subject.

(760) A. B. Crawford, "Radar reflections in the lower atmosphere," PROC. I.R.E., vol. 37, pp. 404–405; April, 1949.
(761) A. W. Friend, "Theory and practice of tropospheric sounding by radar," PROC. I.R.E., vol. 37, pp. 116–130; February, 1949.
(762) V. A. Krasilnikov, "The effect of pulsations of refractive index of the atmosphere on the propagation of ultra-short waves," *Bull. Acad. Sci.* (USSR), vol. 13, pp. 33–57; 1949 (In Russian). Abstract in English, PROC. I.R.E., vol. 37, p. 972; August, 1949.

Velocity of Propagation. Certain Shoran observations between very accurately surveyed points indicated that the velocity of radio waves in vacuo should be increased by 16 kilometers per second over the previously accepted most accurate value for the velocity of light in vacuo.

Measurements at microwave frequencies with the Oboe system have disclosed the change in velocity of propagation with the height of the aircraft over an air-to-ground path. Values somewhat greater than that accepted have been reported.

A new optical determination of the velocity of light in vacuo was published in Sweden, which is in good agreement with the new Shoran value.

(763) C. I. Aslakson, "Can the velocity of propagation of radio waves be measured by Shoran?" *Trans. Amer. Geophys. Union*, vol. 30, pp. 475–487; August, 1949.
(764) F. E. Jones and E. C. Cornford, "The measurement of the velocity of propagation of centimeter radio waves as a function of height above the earth. Part 2—The measurement of the velocity of propagation over a path between ground and aircraft at 10,000, 20,000, 30,000 ft.," *Jour. IEE* (London), vol. 96, part 3, pp. 447–452; September, 1949.
(765) E. Bergstrand, "A preliminary determination of the velocity of light," *Ark. Mat. Astr. Fys.*, vol. 36A, no. 20; 1949. (See also *Nature* (London), vol. 163, p. 338; February 26, 1949).

Atmospheric Attenuation. The absorption of microwaves by the oxygen and water vapor of the air will probably set the limit to the upward expansion of the radio spectrum for communication purposes. The subject interests physicists also because it makes possible for the first time a thorough experimental study of the effect of pressure on the shape of the absorption lines. The first out-of-doors measurement of the atmospheric attenuation of millimeter waves by oxygen was reported.

Laboratory measurements of absorption of 5-millimeter waves by pure oxygen at atmospheric pressure were reported. Partial resolution of the spectral lines was achieved. The precise frequencies of the lines at low pressures remain to be determined, as well as an understanding of the observed unexpected nonlinear variation of absorption with partial pressure of oxygen.

(766) H. R. L. Lamont, "Atmospheric absorption of the millimeter waves," *Proc. Phys. Soc.* (London), vol. 61, pp. 562–569; December, 1948.
(767) M. W. P. Strandberg, C. Y. Meng, and J. G. Ingersoll, "The microwave absorption spectrum of oxygen," *Phys. Rev.*, vol. 75, pp. 1524–1528; May 15, 1949.

Radio Astronomy

Galactic Radio Waves. An important development was the announcement by the Australians of radio waves coming from the Crab nebula. These measurements were the first to relate a source of radio waves to any visible celestial object other than the sun. A further list of possible celestial point sources was given by Hey. Work at Manchester and Cambridge, England, showed that the variability of the point source in Cygnus is not coherent at the two localities, but only over distances of a mile or so. Thus, this phenomenon is one superimposed by the atmosphere or, probably, ionosphere of the earth. It was suggested that the radio-frequency radiation is produced in late-type stars by flare activity similar to that of the sun but on a scale roughly 10^{11} times larger. Least-squares solutions of observations at 160 and 480 megacycles indicated the plane of the galaxy to be inclined to the visual galactic equator by 1.61 and 0.72 degrees, respectively.

(768) J. G. Bolton, G. J. Stanley, and O. B. Slee, "Positions of three discrete sources of galactic radio-frequency radiation," *Nature* (London), no. 4159, pp. 101–102; July 16, 1949.
(769) J. S. Hey, "Point sources of radio waves," *Observatory*, vol. 49, no. 849; April, 1949.
(770) A. Unsold, "Origin of the radio-frequency emission and cosmic radiation in the Milky Way," *Nature* (London), vol. 163, pp. 489–491; March 26, 1949.
(771) Ruth J. Northcott and Ralph E. Williamson, "Galactic noise and the plane of the galaxy," *Jour. Roy. Astr. Soc. Canada*, vol. 42, pp. 269–279; November–December, 1948.

Solar Radio Waves. Solar noise at 10.7 centimeters showed that the radiation from the quiet sun is randomly polarized, whereas sunspots can produce circularly polarized radiation. The daily mean intensity of solar radiation on 10.7 centimeters was compared to relative sunspot numbers. The correlation coefficients increase with successive comparisons. It was suggested that the radiation consists of: (1) a continuous background corresponding to an apparent temperature near 60,000 degrees and due to free transitions in the chromosphere and corona, (2) a slowly variable component dependent on the sums of the areas of the spots, and (3) sharp increases of intensity usually related to modifications in the topography of spots or spot groups.

Observations during a partial eclipse of the sun were inconclusive in determining whether the sun appears in the centimeter band as a brilliant ring. The fact that bursts of solar noise were not observed coinciding with a particular intense solar flare suggests that certain magnetic conditions are also required in the production of solar noise.

The theory of oscillations of an unbounded plasma was extended to consider the effects of collisions and special groups of particles having well-defined ranges of velocities. The latter produced a tendency toward an instability that may be responsible for solar and galactic radio noises.

The formulas for the radiation of long-wave energy from an ionized medium were modified to treat cases in which the index of refraction of the medium differs considerably from unity. For the solar corona the radiation so derived can be five times weaker than that calculated from the unmodified formulas, and concepts regarding the effective level observed on a given frequency must be revised.

The theory of generation of radio energy resulting from space-charge interaction between streams of charged particles was applied to the problem of solar radio noise. Interaction of two streams may not be required for the generation but may serve to amplify the solar noise.

(772) A. E. Covington, "Circularly polarized solar radiation on 10.7 centimeters," Proc. I.R.E., vol. 37, p. 407; April, 1949.
(773) J. F. Denisse, "Relation entre les emissions radioélectriques solaires decimentriques et les taches du soleil," *Compt. Rend.* (Paris), vol. 228, pp. 1571–1572; May 16, 1949.
(774) M. Laffineur, R. Michard, J. L. Steinberg, and S. Zisler, "Observations radioélectriques de l'eclipse de soliel du 28 Avril 1948," *Compt. Rend.* (Paris), vol. 228, pp. 1636–1637; May 23, 1949.
(775) N. W. Newton, "Solar notes," *Observatory*, vol. 69, pp. 74–75; April, 1949.
(776) "Royal Astronomical Society, Meeting of 1949 March 11," *Observatory*, vol. 69, pp. 47–54; April, 1949.
(777) D. Bohm and E. P. Gross, "Theory of plasma oscillations. B. Excitation and damping of oscillations," *Phys. Rev.*, vol. 75, series II, pp. 1864–1876; June 15, 1949; abstracted under subtitle in *Phys. Rev.*, vol. 75, series II, p. 1323; April 15, 1949.
(778) J. F. Denisse, "Influence de l'indice de réfraction sur les emissions radioélectriques d'un milieu ionisé," *Compt. Rend.* (Paris), vol. 228, pp. 751–753; February 28, 1949.
(779) A. V. Haeff, "On the origin of solar radio noise," *Phys. Rev.*, vol. 75, series II, pp. 1546–1551; May 15, 1949; abstracted in *Phys. Rev.*, vol. 75, series II, p. 1333; April 15, 1949; and, with minor variations, in Proc. I.R.E., vol. 37, p. 172; February, 1949.
(780) V. A. Bailey, "Space-charge wave amplification effects," *Phys. Rev.*, vol. 75, series II, pp. 1104–1105; April 1, 1949.

Reviews. A number of review articles on radio astronomy appeared during the year.

(781) C. R. Burrows, "Radio astronomy," *Electronics*, vol. 22, pp. 75–79; February, 1949; reprinted as Cornell University, School of Electrical Engineering, Radio Astronomy Report No. 3.
(782) A. C. Clarke, "The radio telescope," *Jour. Brit. Astr. Assn.*, vol. 59, pp. 156–159 (and discussion under different title on pp. 146–148); April, 1949.
(783) M. A. Ellison, "Solar flares and their terrestrial effects," *Nature* (London), vol. 163, pp. 749–753; May 14, 1949.
(784) W. Menzel, "Recent results of solar investigations," *Elek. Wiss. Tech.*, vol. 3, pp. 55–61; February, 1949.
(785) G. Reber, "Galactic radio waves," *Sky and Telescope*, vol. 8, pp. 139–141; April, 1949.
(786) "Symposium: Microwave astronomy," *Astr. Jour.*, vol. 54, pp. 121–122; April, 1949. (J. L. Greenstein, "The origin of galactic radio noise"; J. P. Hagen, "The measurement of extraterrestrial radio wave emission.")

Ionospheric Propagation

Theoretical advances were made in the fields of solar relationships, oblique-incidence propagation, and electron distribution in the ionosphere.

(787) C. W. Allen, "Critical frequencies, sunspots, and the sun's ultra-violet radiation," *Terr. Mag. Atmo. Elec.*, vol. 53, pp. 433–448; December, 1948.
(788) H. G. Booker, "Application of the magneto-ionic theory to radio waves incident obliquely upon a horizontally stratified ionosphere," *Jour. Geophys. Res.*, vol. 54, pp. 243–274; September, 1949.
(789) L. A. Manning, "The reliability of ionospheric height determinations," Proc. I.R.E., vol. 37, pp. 599–603; June, 1949.
(790) O. E. H. Rydbeck, "On the propagation of waves in an inhomogeneous medium," Report No. 7, Research Laboratory of Electronics, Chalmers University of Technology, Gothenburg, Sweden.
(791) N. C. Gerson, "Maintenance of nocturnal ionization," *Nature* (London), vol. 163, p. 491; March, 1949.
(792) H. Bremmer, "Some remarks on the ionosphere double refraction," *Philips Res. Rep.*, Part I, vol. 4, pp. 1–19; February, 1949.
(793) H. Bremmer, "Some remarks on the ionosphere double refraction," *Philips Res. Rep.*, Part II, vol. 4, pp. 189–205; June, 1949.
(794) R. Payne-Scott and L. L. McCready, "Ionospheric effects noted during dawn observation on solar noise," *Terr. Mag. Atmo. Elec.*, vol. 53, pp. 429–432; December, 1949.
(795) R. Penndorf, "The vertical distribution of atomic oxygen in the upper atmosphere," *Jour. Geophys. Res.*, vol. 54, pp. 7–38; March, 1949.

A rebirth of interest in ionosphere behavior below one megacycle is currently providing information on the detailed structure of the *E* region, and higher strata as well.

(796) R. A. Helliwell, "Ionospheric virtual-eight measurements at 100 kilocycles," Proc. I.R.E., vol. 37, pp. 887–894; August, 1949.

Considerable work continued in the investigation of the effects of atmospheric tidal oscillations.

(797) D. F. Martyn, "Atmospheric tides in the ionosphere: Part 3—Lunar tidal variations at Canberra," *Proc. Roy. Soc. A*, vol. 194, pp. 429–444; November 9, 1948.
(798) D. F. Martyn, "Atmospheric tides in the ionosphere: Part 4—Studies of the solar tide, and the location of the regions producing the diurnal magnetic variations," *Proc. Roy. Soc. A*, vol. 194, pp. 445–463; November 9, 1948.
(799) D. F. Martyn, "Lunar variations in the principal ionospheric regions," *Nature* (London), vol. 163, pp. 34–36; January 1, 1949.
(800) A. G. McNish and T. N. Gautier, "Theory of lunar effects and midday decrease in F_2 ion-density at Huancayo," *Jour. Geophys. Res.*, vol. 54, p. 181; June, 1949.

From analysis of fading phenomena and of rapidly moving disturbances in sweep-frequency virtual-height records, methods of determining wind and pressure-wave velocities were suggested.

(801) J. A. Ratcliffe, "Diffraction from the ionosphere and the fading of radio waves," *Nature* (London), vol. 162, pp. 9–11; July 3, 1948.
(802) G. H. Munro, "Short-period changes in the *F* region of the ionosphere," *Nature* (London), vol. 162, pp. 886–887; December 4, 1948.
(803) G. H. Munro, "Short-period variations in the ionosphere," *Nature* (London), vol. 163, pp. 812–814; May 21, 1949.
(804) W. J. G. Beynon, "Evidence of horizontal motion in region F_2 ionization," *Nature* (London), vol. 162, p. 887; December 4, 1948.

(805) S. N. Mitra, "A radio method of measuring winds in the ionosphere," *Proc. IEE* (London), vol. 96, pp. 441–446; September, 1949.

Study of meteoric ionization brought forth new means of obtaining both meteoric velocities and radiants and new ways of studying ionospheric structure.

(806) P. M. Millman and D. W. F. McKinley, "Three-station-radar and visual triangulation of meteors," *Sky and Telescope*, vol. 8; March, 1949.
(807) D. W. F. McKinley, "A phenomenological theory of radar echoes from meteors," PROC. I.R.E., vol. 37, pp. 364–375; April, 1949.
(808) L. A. Manning, O. G. Villard, Jr., and A. M. Peterson, "Radio doppler investigation of meteoric heights and velocities," *Jour. Appl. Phys.*, vol. 20, pp. 475–479; May, 1949.
(809) D. D. Cherry and C. S. Shyman, "On meteor speed measurements by the radio doppler method at low frequencies," *Phys. Rev.*, vol. 75, pp. 1441–1442; May 1, 1949.
(810) J. G. Davies and C. D. Ellyett, "The diffraction of radio waves from meteor trails and the measurement of meteor velocities," *Phil. Mag.*, vol. 40, pp. 614–626; June, 1949.
(811) E. Eastwood and K. A. Mercer, "A study of transient radar echoes from the ionosphere," *Proc. Phys. Soc.* (London), vol. 61, pp. 122–134; August, 1948.

Many groups have been studying long-scatter, multipath, and oblique-incidence propagation effects, although most of the results have not yet been published.

(812) A. H. Benner, "Predicting maximum usable frequency from long-distance scatter," PROC. I.R.E., vol. 37, pp. 44–47; January, 1949.
(813) W. L. Hartsfield, S. M. Ostrow, and R. Silberstein, "Backscatter observations by the Central Radio Propagation Laboratory, August 1947–March 1948," Report CRPL-5-5, National Bureau of Standards, Central Radio Propagation Laboratory, Washington, D. C.; October, 1948.
(814) W. J. G. Beynon, "Propagation of radio waves," *Wireless Eng.*, vol. 25, pp. 322–330; October, 1948.

Solar flares, absorption, and interaction of waves received further attention.

(815) O. E. H. Rydbeck and D. Strauz, "Ionosphere effects of solar flares 1948," *Trans. Chalmers Univ. of Techn.*, NR83.
(816) J. E. Hacke, Jr., and J. M. Kelso, "An approximate solution of the problem of path and absorption of a radio wave in a deviating ionosphere layer," PROC. I.R.E., vol. 36, pp. 1477–1481; December, 1948.
(817) J. A. Radcliffe and I. J. Shaw, "A study of the interaction of radio waves," *Proc. Roy. Soc.*, vol. 193, pp. 311–343; 1948.
(818) L. G. H. Huxley, H. G. Foster, and C. C. Newton, "Measurements of the interaction of radio waves in the ionosphere," *Proc. Roy. Soc.*, vol. 61, pp. 134–146; August, 1948.

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Pictorial Display in Aircraft Navigation and Landing*

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Summary—**The 15-year general plan formulated by the Radio Technical Commission for Aeronautics for developing and installing a comprehensive air-navigation system in the United States requires, among other things, ground and airborne "pictorial situation display." This display is to appear on the ground and in aircraft cockpits, and is to be used in the traffic-control zone, during landing, and to control taxiing on the surface of the airport.**

Displays for traffic control and instrument landing are illustrated. It is shown that, in traffic control, the picture can be used merely as a means of monitoring some other method of control and of enabling the pilot to avoid collisions with other aircraft; or the picture can constitute the primary method of presenting traffic-control instructions to the pilot. Moving-block and fixed-block traffic-control patterns were flown by many pilots in a teleran Link trainer with favorable results.

Teleran is discussed to indicate the nature and solution of some problems typical of pictorial display in aviation. Developments are described pertaining to self-identification in the picture, use of graphechon storage tubes, altitude coding, and picture brightness.

After additional and varied developments, requiring several years for completion, it should be possible to select optimum methods for providing pictorial display.

THE EVER-INCREASING military, civil, and commercial importance of air transportation is widely recognized. In the United States alone at least five thousand engineers are engaged in the development and design of air frames and engines. The efforts of these men and their predecessors have resulted in remarkable increases in the speed, economy, and mechanical reliability of air transportation, but poor weather causes too many aircraft to spend too much time on the ground. It causes others to spend too much time in the air because of congestion in the air lanes and on the runways.

It is interesting to note that the over-all problem of controlling, in three-dimensional air space filled with fog, the positions of numerous aircraft having different speed and maneuverability characteristics and different destinations poses a complex and challenging technical problem. All workers in this field have recognized that only electronic methods are likely to result in a satisfactory solution. In the last few years, the over-all problem was for the first time approached from the true systems viewpoint. Though many operational requirements were unspecified (some are still under study) and thus had to be estimated, several noteworthy systems developments were conducted in industrial laboratories, generally under the financial sponsorship of the United States Air Force. In 1947, when RTCA prepared recommendations[1] "for the safe control of expanding air traffic," the major systems and methods under development were teleran,[2–5] navar,[6] lanac,[7,8] GRS block,[9] and tricon.[10,11] The RTCA recommendations are now serving as a nonobligatory guide for the permanent Air Navigation Development Board. The recommendations, too lengthy for presentation here, specify a "transition" system and an ultimate or "common" system. Pictorial situation display is incorporated in the common system.

The pictorial display, a new concept in aircraft flight, is recommended for all segments of flight and on the ground (take-off, terminal zone, en route, initial approach, final approach, landing, movement on the ground), and it is recommended that display equipment be designed to fit all types of aircraft. Thus, pilots will someday have a new instrument which will produce a relatively large quantity and variety of information in diagrammatic or pictorial manner. It is the authors' contention that the value of pictorial presentation is, even today, only partly realized, and that actual flight experience may well prove that the picture itself can constitute the major facility for many of the operational functions herein considered. Since teleran (a generic word from *tele*vision-*r*adar-*a*ir-*n*avigation) provides pictorial situation display to the extent recommended by RTCA, a brief description of it may be of interest at this point.[12]

TELERAN

The basic concept of teleran is that all information necessary for general navigation, traffic control, collision prevention, landing, taxiing control, and weather depiction should be obtained on the ground and should be automatically combined into convenient pictorial dis-

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1 "Air traffic control," Radio Technical Commission for Aeronautics, paper 27-48-DO-12; May, 1948.

2 P. J. Herbst, I. Wolff, D. Ewing, and L. Jones, "The teleran proposal," *Electronics*, vol. 19, pp. 125–127; February, 1946.

3 D. H. Ewing and R. W. K. Smith, "Teleran; air navigation and traffic control by means of television and radar," *RCA Rev.*, vol. 7, pp. 601–620; December, 1946.

4 L. F. Jones, "Teleran system of air navigation and traffic control" (abstract), *Aeronaut. Eng. Rev.*, vol. 5, December, 1946.

5 D. H. Ewing, H. J. Schrader, and R. W. K. Smith, "Teleran; first experimental installation," *RCA Rev.*, vol. 8, pp. 612–622; December, 1947.

6 H. Busignies, P. R. Adams, and R. I. Colin, "Aerial navigation and traffic control with navaglobe, navar, navaglide, and navascreen," *Elec. Commun.*, June, 1946.

7 K. McIlwain, "Hazeltine lanac system of navigation and collision prevention," *Proc. Radio Club of America*, February, 1949.

8 "Lanac, two-signal navigation system," *Tele-Tech*; February, 1947.

9 "The block system for airway control," *Electronic Ind.*; December, 1946.

10 "They call it tricon; General Electric's triple coincidence electronic method of air navigation," *Aero Digest*; April–May, 1948.

11 A. Francis, "Tricon—new system for airplane navigation," *Tele-Tech*; November, 1947.

12 The desirability of pictorial presentation was pointed out by V. K. Zworykin and A. N. Goldsmith, independently, more than fifteen years ago. Subsequent developments in ground radar and airborne transponders were necessary before it was possibile to devise an integrated, comprehensive, and practical system.

plays. These displays are then used on the ground, and also are continuously and simultaneously transmitted to all aircraft by television techniques. Altitude segregation is used so that the displays presented to ground and airborne personnel contain only relevant information. The composite picture for each altitude layer is produced by combining ground radar information regarding the location of all aircraft with map information and diagrammatic traffic-control displays and other visual data. Altitude-coded airborne transponders are employed so that the radar data can be automatically and accurately sorted by altitude layers. The airborne equipment consists of only the transponder and a picture receiver. Means are provided to show each pilot continuously which of the aircraft in the received composite picture is his own. Fig. 1 illustrates the main elements of the system. Time-division multiplex transmission is used so that a single transmitter for each control center can continuously provide the pictures for all altitude layers, for weather maps, for traffic control, etc.

The instrument-landing situation is presented pictorially by means of data obtained from precision-beam radar (GCA) equipment. The picture received in the cockpit depicts position with respect to the glide path (horizontally and vertically), with respect to the airport, and with respect to other aircraft on the glide path.

Traffic control by several methods is made possible through the flexibility of pictorial presentation. Weather map reception is easily provided.

The pictorial display is transmitted by means sufficiently independent of other parts of the system that elements of the system are not so mutually interdependent as to limit their continuing improvement. For example, as the art progresses, improvements can be made in the ground radar characteristics, in traffic-control techniques (as required by evolution in the traffic situation), in instrument-landing displays, and in airport-taxiing control, without obsoleting or modifying the ground-to-aircraft picture link. By using storage tubes both on the ground and in the aircraft, in the manner described later, large savings in bandwidth are made possible.

Typical Operational Uses of Pictorial Display

Several of the operational aspects of pictorial display will serve to illustrate the flexibility and broad utility of such displays.

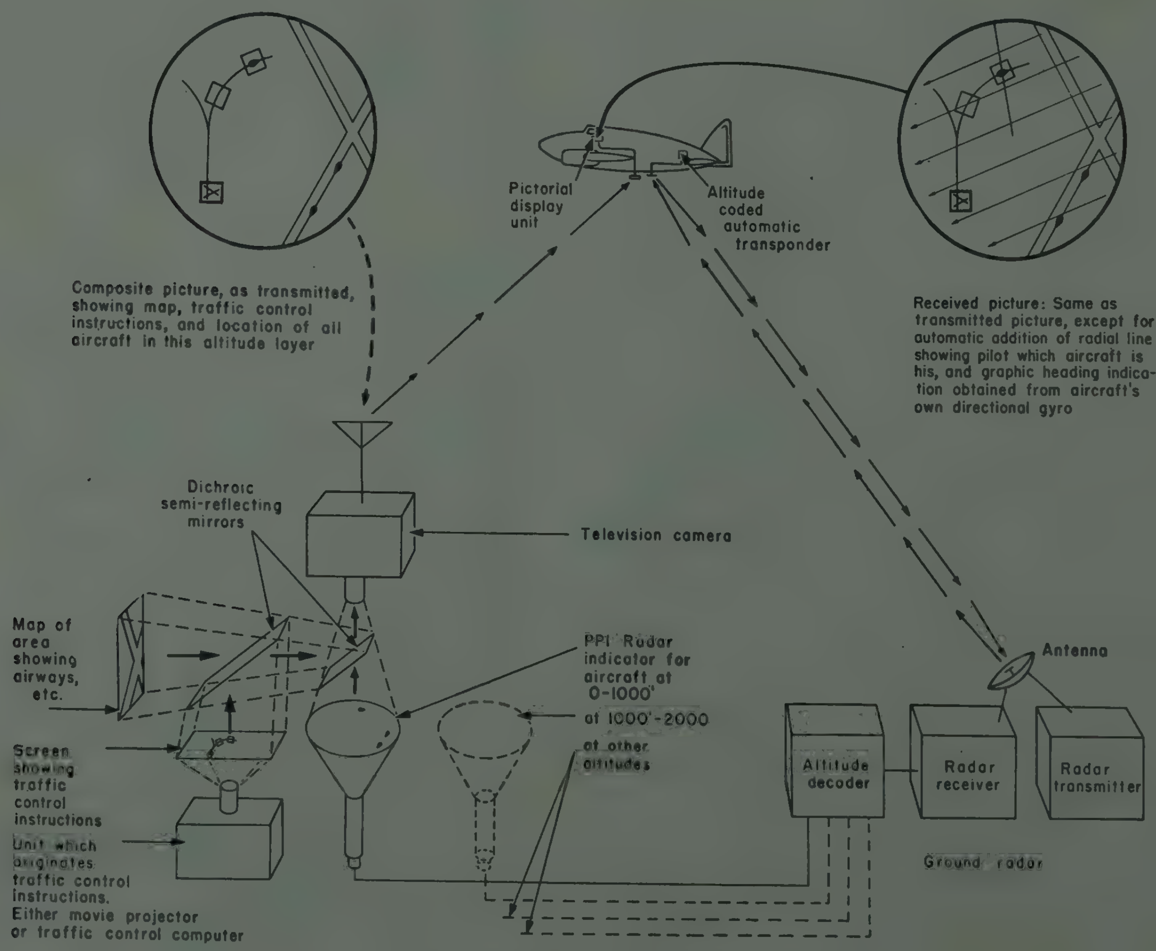

Fig. 1—Essential elements of pictorial display system.

1. Graphic Presentation of Aircraft Heading

It is desirable to add to the picture received from the ground, by superposition, information regarding the heading of the aircraft. A map-like picture gives displacement information only. This is not sufficient to permit a pilot on manual control to fly a straight track, since some displacement from the track must be discerned before corrective action is taken, resulting in a zigzag flight path. The desired linearity of flight path is realized by the pilot's holding a steady heading as indicated by the gyrocompass. To obviate the necessity of shifting sight back and forth between the pictorial display and the gyrocompass, a transparent overlay disk ruled with parallel lines is mounted immediately in front of the display tube and is rotated through a servomechanism by the compass. Thus, without glancing away from the picture, the pilot at all times sees heading information superimposed on the picture in graphic form. An azimuth scale around the picture-tube periphery permits reading the heading in degrees when desired. Experience in a teleran trainer has shown that this graphic method of indicating heading is very desirable.

2. Short-Range Navigation

An important operational use is in short-range navigation. Fig. 2 depicts a received picture typical of a general navigation situation. Airways, obstacles, airports, and other aircraft are shown. With just the basic display, including the heading indicator, it is interesting to note that for all short-range flight functions the single pictorial display instrument makes it unnecessary for the pilot to use his automatic direction finder, standard-range receiver, omnirange receiver, distance-measuring equipment, directional gyro (except to occasionally correct for precession), maps, and instrument-landing system. In addition, the picture provides other important services such as weather-map reception and collision prevention.

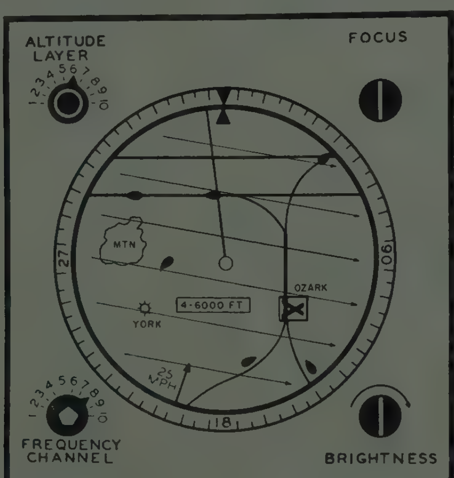

Fig. 2—Typical navigation picture includes pilot's own aircraft (identified by radial line), other aircraft, air routes, obstruction, airport, etc.

3. Traffic Control in the Initial Approach Zone

Before briefly discussing several ways in which pictorial display can be used to directly control aircraft traffic in the initial approach zone, it should be noted that, in case other means of direct control are employed, pictorial display can perform the important function of monitoring. A pilot whose aircraft is under the control of relatively complicated ground equipment will feel confidence in the operation of this equipment only if he is able to monitor its performance and the status of his flight by independent means. A pictorial situation display not only would provide him at a moment's glance with a complete check of the operation of the over-all system, but, furthermore, would enable him to take emergency action when desired. Only the picture will tell him the location of other aircraft and of ground-based obstacles. For a more thorough discussion of the traffic-control problem and its relationship to pictorial presentations, reference should be made to a separate paper[13] describing specific methods for using pictorial display in the direct control of traffic.

In the initial approach zone, two general methods are available for traffic control. One employs "fixed blocks" wherein blocks of air space are at fixed locations with respect to the ground. The other uses "moving blocks" wherein reserved air spaces constantly move in accordance with the intended motion of aircraft. Fig. 3 depicts one form of fixed-block traffic control for the New York area. It will be noted that this particular picture is the one transmitted for southeast wind conditions. It shows all necessary landing paths for medium-speed aircraft arriving from the four approach directions, for any of the three New York fields. High-speed aircraft would see different series of blocks except for the final convergence, and a still different picture would be transmitted for low-speed aircraft. The complexity of the traffic situation in the New York area is the greatest in the world, and it should be realized that much simpler pictures than Fig. 3 will suffice in most locations. In addition to the pictorial display, traffic-control computers and other facilities not described in this paper will be required.

If the moving-block principle is used, the automatic traffic-control computer on the ground is designed to produce and insert into the picture appropriate moving blocks. Each aircraft is assigned to a moving air space. Proposals and studies by the authors, continued under contract at Franklin Institute,[14] showed that it is practical to design a computer which will immediately assign a block to an aircraft upon its entry into the control zone, and then will so control the speed of the block in the picture (within the normal speed range of the aircraft) that the block will be brought to the final approach (start of glide path) with minimum delay, yet

[13] Loren F. Jones, "Traffic control by pictorial display," *Aeronaut. Eng. Rev.*, vol. 8, pp. 22–33; February, 1949.
[14] W. W. Felton, "The application of a moving block system to RCA teleran," Franklin Institute Report; December, 1947.

with proper spacing from preceding and following blocks. The pilot need merely keep his aircraft within the block as seen in his pictorial display. About 100 pilots have flown this variable-speed, curved-path, moving-block method in a teleran Link trainer. They commented very favorably. However, no attempt was made to compare moving blocks with fixed blocks.

Fig. 4 shows an installation in a C-47 cockpit. It includes an unretouched photograph of data transmitted through a pictorial system.

4. Automatic Moving Blocks for Nonscheduled Aircraft

Through the flexibility of the pictorial method, certain nonscheduled aircraft (chartered planes, larger sized private planes, military aircraft and cargo aircraft, some of which will operate off the established airways) can be rendered a unique service. Such aircraft already exceed commercial scheduled aircraft in number and in hours flown. In the future in the United States, it is likely that nonscheduled aircraft will frequently employ separate airports, adequately spaced from those used by scheduled airlines. To avoid prescheduling and other complications, nonscheduled air-

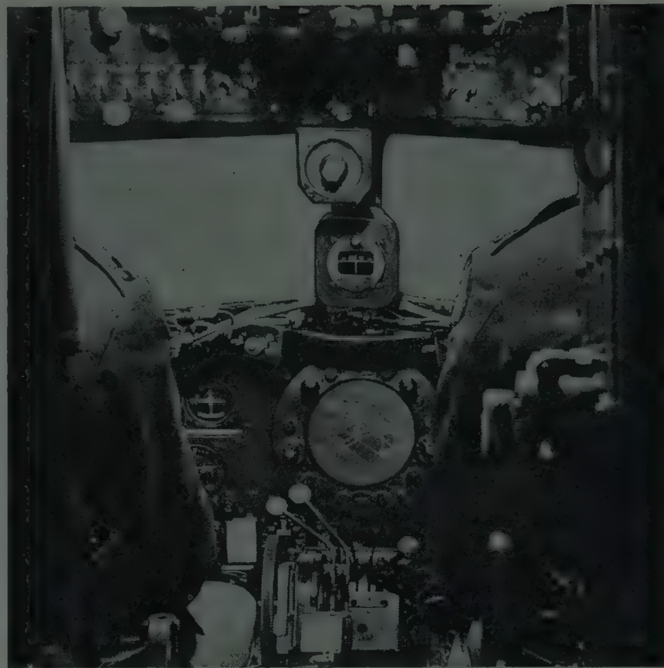

Fig. 4—An installation of a teleran indicator in a C-47 cockpit. The picture on the tube is an actual photograph of a moving-block diagram transmitted through a pictorial display system.

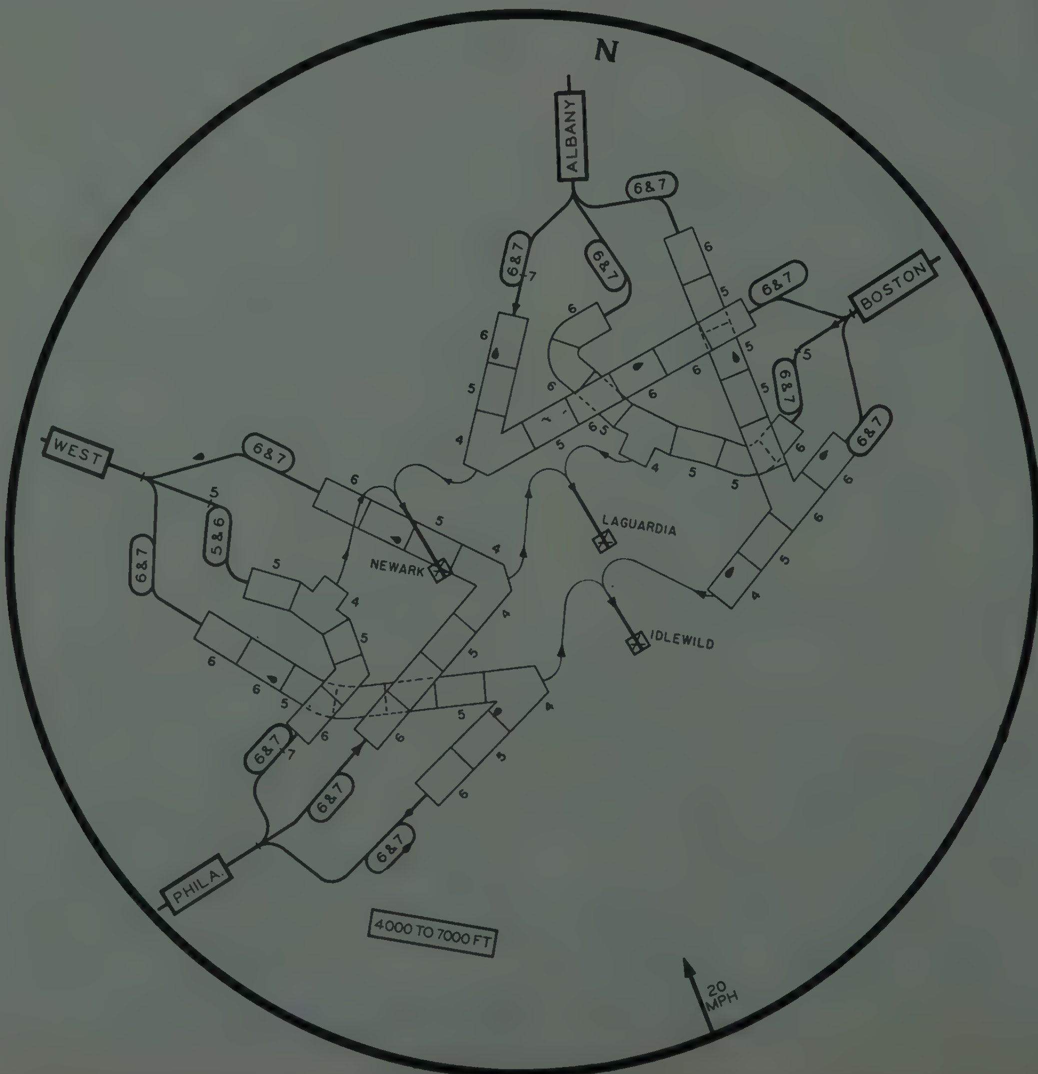

Fig. 3—Suggested approach paths to the three New York airports.

craft may fly off the established airways and may land at these nonscheduled airports. According to the RTCA recommendations, the established airways start at certain minimum altitudes and thus can be "crossed" without notice at low altitudes. But before a nonscheduled aircraft can fly to a nonscheduled airport with only the simplest advance clearance, the pilot must know that there is some means at the terminal airport for the orderly handling of traffic arriving at almost random timing. One method of accomplishing this is to add to the situation display transmitted from the terminal airport a set of moving blocks which would look like moving images on animated film. In fact, the blocks would originate on closed loops of animated film placed in the ground picture transmission equipment. Practical means for accomplishing this are available. No traffic-control computer is needed. Peculiarly shaped blocks are desirable in order to accommodate both slow and fast aircraft. The blocks move constantly along the approach paths and down the glide path. Somewhat similar blocks move away from the airport for take-off. The entire process is continuous, much as is a moving stairway.

Changes in wind direction, requiring the use of a different runway, can be indicated in a few minutes' time by the simple expedient of transmitting a transition film whose animation is specifically intended for the particular transition required. After the transition is completed, a "steady wind" film is repeatedly scanned for the new runway until another change is indicated. Fig. 5 typifies a runway shift.

The successive scenes in this illustration are spaced about one minute apart. It will be noted that the entire runway shift requires about six minutes. Aircraft *A* completes its landing within the six-minute period, whereas aircraft *B* follows shortly afterward on the new runway.

With this "moving stairway" technique, minimum skill and attention are required on the part of the pilot, and still less attention is required on the part of ground personnel. Yet, unless the airport is operated too near to saturation, aircraft of several speed capabilities and with random arrival times from any direction are handled with little delay. This nearly automatic, economical method may prove to be desirable at some of the more isolated smaller airports.

5. *Instrument Landing*

After an aircraft has completed its initial approach, either by fixed- or moving-block or some other method, it undertakes an instrument landing. It is during this part of an aircraft's flight, when it is traveling at reduced speed and when all aircraft which are to land are converging on the same glide path, that the spacing between adjacent aircraft is intentionally at minimum. At this time it is especially important that each pilot know the location of other aircraft ahead of and behind him on the glide path. To date, pictorial display is the only method proposed which gives the pilot this information.

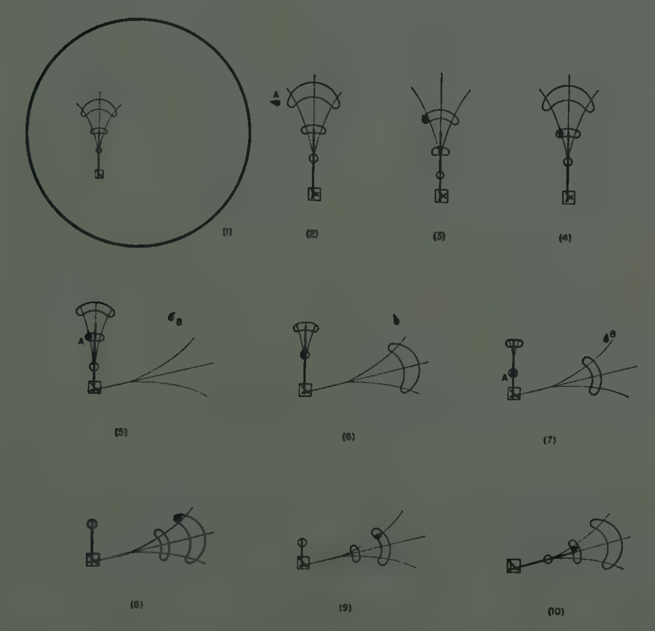

Fig. 5—Display (1) depicts the relative size of the "moving stairway" traffic-control pattern in the complete pictorial display picture. In (2), (3), (4), etc., aircraft *A* flies within one of the moving blocks (originating from animated film transmitted from the ground) and proceeds to its landing. In (5), pilots of other aircraft such as *B* are shown that a change in runway has been necessitated by wind shift. Succeeding scenes show how plane *B* proceeds to land on the new runway. (5) to (9) inclusive are produced by a transition film for runway shift. (10) is the start of a steady wind film for the new runway.

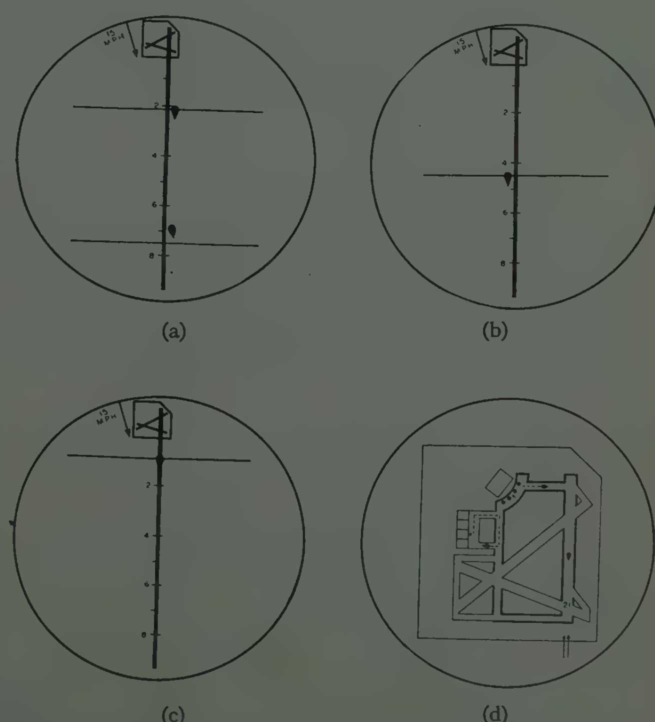

Fig. 6—Four successive pictorial displays during the landing process. In (a), the plane 7 miles from the airport is slightly to the right and slightly above the glidepath (another plane is 2 miles from the airport). In (b), the plane has proceeded to 4½ miles from the airport and is at corrected altitude, but a little to the left. In (c), it is 1 mile from the airport and is exactly on the glidepath. Upon contacting the runway, the pilot shifts to picture (d) which shows the situation on the airport surface.

There are several convenient manners in which pictorial display can present instrument-landing information. One method is shown in Fig. 6. This particular method has been flown by 80 pilots in a teleran Link trainer. The successive scenes in Fig. 6 indicate an approach over an eight-mile glide path. Note that the pilot still sees his aircraft as a spot moving on a map. Added, however, is an automatically produced horizontal line which indicates whether the aircraft is above or below the glide path.

6. *Taxiing Control*

Finally, after the aircraft is on the ground, possibly a mile from the ramp or hangar, means must be provided for controlling the surface traffic so that under true zero-zero conditions taxiing can be accomplished expeditiously and safely. RTCA considered that, under conditions of poor visibility, pictorial situation display is the only known future means for making possible the adequate control of traffic on the airport surface.

7. *Weather-Map Reception*

The appropriateness of pictorial display for presenting weather data in easily understood form is quite apparent. By means of the time-sharing and storage methods discussed below, sufficient channels should be available so that a number of weather maps can be transmitted aloft, each specifically prepared for a given altitude layer.

Other graphical information, such as emergency instructions written in script or drawn in diagrammatic form, can readily be transmitted over the ground-to-air picture circuit. Possibly some of the most useful operational functions to be performed by pictorial display are yet to be proposed.

Equipment Considerations

Several technical aspects of pictorial display will now be described. Most of these technical developments have been tested and studied in the experimental teleran system installed in Washington, D. C., but some of them are new ideas proposed for future investigation. The present system will not be described in detail as this has been done elsewhere.[2-5]

In the Washington, D. C., experimental installation there are two ground installations, one representing an airway control center, the other an airport control center. The airway control center transmits separate pictures for three altitude layers (through three "altitude consoles") as well as a weather map. It operates in conjunction with a long-range search radar which interrogates the airborne transponders. The airport control center includes two altitude consoles operating from a short-range search radar, and an approach console operating from a GCA precision radar. "Self-identification" signals are incorporated in the transmissions from both stations.

1. *Transmission Considerations*

A ground console is provided for each altitude layer and for the weather map. These consoles contain means for converting the desired information into televsion video information, as well as a display tube to present the information to ground control personnel.

Since it is highly desirable to transmit the multiplicity of information in a minimum bandwidth, the method known as time sharing or time multiplexing is used. With one picture sent from each console in a cyclical order, a bandwidth of 10 megacycles is required for, say, 20 consoles providing 20 pictures of high definition. (As will be shown later, the bandwidth can be further economized through the use of storage tubes.) Time sharing is permissible as long as the cycle time is shorter than the radar scanning rate, that is, a new picture is transmitted at least as often as new radar data are available. Switching circuits connect each console to the video output circuits in the proper order, and, as the correct frame must be selected in the aircraft, a code identifying the following frame is sent during the vertical blanking time. The vertical sync pulse is a horizontal sync pulse identified from other horizontal sync pulses by being 10 microseconds wide as compared to 2 microseconds for the other horizontal sync pulses. (See Fig. 7.) The nth horizontal sync pulse after the vertical sync is also made 10 microseconds wide to identify the nth frame in the time-sharing cycle. In the airborne receiver, a selector switch sets up a decoder so that the receiver is "enabled" for one frame after the correct code is received.

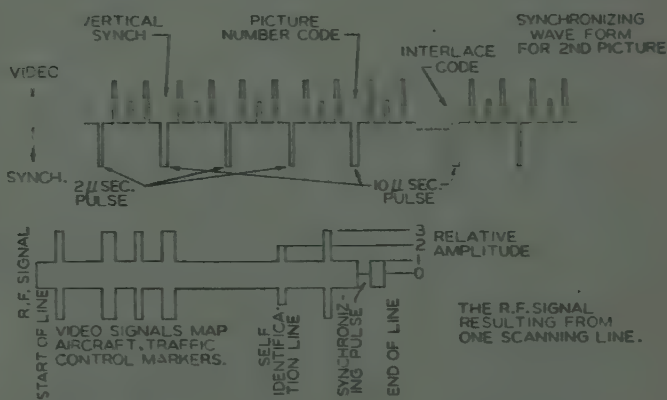

Fig. 7—Television synchronizing wave form and picture identification code.

The video signals which modulate the transmitter are clipped so there will be no variation in signal level, only "off" and "on" video conditions. The zero signal level is 30 per cent of maximum output of the transmitter. Sync signals are transmitted as negative modulation, and video is transmitted as positive modulation.

2. *Self-Identification*

The absence of intermediate signal levels opens the possibility of sending two video signals on the same car-

rier but distinguished by different amplitudes. Advantage is taken of this feature in producing the self-identification line, which is a radial line from the center of the picture passing through the response of the aircraft in which the signals are being received. This line is generated at the ground station by a flying spot scanner and has at all times the same bearing as the radar beam. This video signal is transmitted at half the amplitude of the picture video and a clipping circuit in the television receiver normally prevents its being seen. The half-amplitude signals are completely separated from the normal video and are enabled only when the aircraft transponder is triggered by the rotating radar beam. At this triggering, one complete field of half-amplitude signal is passed so that the line which appears must pass through the response of the aircraft in the beam at that time. The normal video, which may be an undesired field, is not enabled by this gate.

3. *Airborne Display and Picture Repetition Rate*

The kinescope used in the airborne receiver has a high-efficiency phosphor which at 14 kv gives a brilliance sufficient for daylight viewing. The persistence of the phosphor is such that a signal is visible for about one-fifth of a second after stimulation. The television pictures are presently transmitted at 45 frames per second, and thus can be time-shared at the present rate of 4 to 1 without serious flicker.

Let us assume that probable future traffic requirements will necessitate the use of 20 altitude layers, i.e., 20 separate time-shared pictures. If the airway radars have a rotational rate of 15 rpm, or once every 4 seconds, and if the transmitted pictures are to follow the aircraft movement as rapidly as does the radar, 20 pictures must be transmitted in four seconds. This is a rate of 5 pictures per second. During each radar sweep a 400-mph plane would move about $\frac{1}{2}$ mile or $\frac{1}{2}$ per cent of the display diameter. When aircraft travel faster than 400 mph, it will be desirable to utilize radars rotating faster than 15 rpm, which in turn will increase the frame rate to, say, 10 per second.

For approach zone and landing operations, if transmission of the four lower altitude layers were acceptable and if landing pictures from 3 GCA radars at 3 airports in the area were required, the total number of pictures transmitted would be 7. Since this is considerably less than 20 pictures envisioned for airways stations, the repetition rate for each individual picture will be about 3 times higher. This increased picture rate will be suitable for the relatively higher rate of motion of the GCA antennas.

By using a simple type of storage tube in the airborne receiver, 20-to-1 time sharing will become quite feasible at the assumed future frame rate of 10 per second. Although each single picture, such as for a single altitude layer, will arrive at an aircraft only once every 2 seconds (which is as fast as data are collected by the radar), the storage tube will produce repeated and essentially flickerless copy of the input data. By using storage tubes in this manner and by using single sideband transmission, a complete rf signal carrying 20 separate pictures for 20 altitude layers at a rate of 10 frames per second (to allow for future high-speed aircraft) can be accommodated in a band of about 1.5 megacycles.

The present airborne receiver consists of one pressurized unit containing the display components and the 14-kv power supply and another unit containing the video amplifiers, power supplies, decoding circuits for picture selection, and the self-identification line gating circuits. Including the transponder, the complete airborne equipment weighs about 110 pounds. It is expected that further development will permit reducing the over-all weight to about 40 pounds, which should be suitable for all aircraft down to and including the four-passenger category.

4. *Antennas and Frequencies*

The television transmitter, a master oscillator type with three amplifier stages and transmission-line tank circuits, operates on 300 megacycles. The ideal antenna pattern would be omnidirectional in the horizontal plane with a cosec squared pattern in the vertical plane. To approximate this, the present antenna has four dipoles stacked vertically to obtain gain and are fed so that the beam is tilted upward into a flattened cone. Thus, vertical coverage is improved and ground-wave interference effects are reduced. This antenna design, consisting of a vertical cylinder with a vertical slot cut in one side and fed in the center, is known as a pylon. (See Fig. 8.) The horizontal pattern varies by less than 3 db. The horizontal polarization may be a disadvantage as it increases ground reflection, but the antenna has the physical advantage of simplicity and ruggedness.

The transmitter antenna gain is limited to that which will give omnidirectional radiation out to 50 miles and

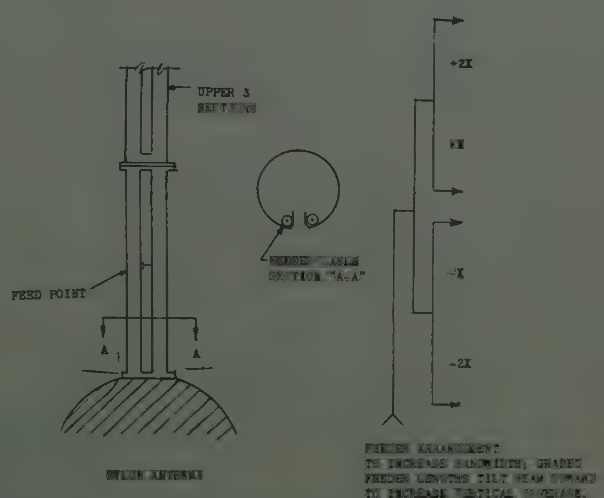

Fig. 8—Pylon antenna at television transmitting station.

up to 30,000 feet in altitude. Since the aircraft receiving antenna must also be omnidirectional, its gain is similarly limited and, in addition, is further limited by the need to allow for changes in the aircraft's attitude. The required transmitter power therefore increases as the square of the frequency. This increased power requirement constitutes a disadvantage to operation in the new air-navigation frequency band between 1,000 and 1,700 megacycles. The storage-tube techniques previously described for reducing the bandwidth will result in a reduction in receiver noise which will largely offset requirements for increased power. Present teleran power, less than one kilowatt peak, gives good performance to 50 miles.

The transponder receiving antennas, X and S band, and transmitting antenna, S band, should all be omnidirectional. The S-band antennas used are simple quarter-wave dipoles mounted under the fuselage. Unfortunately, they do not solve the difficult problem of obtaining omnidirectional operation for all attitudes of the aircraft, and further work on this problem is needed.

5. Altitude Coding

To avoid confusion in the presentation of aircraft location information, it is highly desirable to eliminate all aircraft indications not essential to the particular display being viewed. Separating the airborne and ground displays into altitude layer displays results in considerable simplification. This is accomplished in the teleran system by equipping the aircraft with transponders which, when interrogated, reply with a code indicative of barometric altitude. This method of height finding is of constant accuracy regardless of the distance of the aircraft from the radar station, and, at long distances, it is much more accurate than would be height-finding radars. A transponder system has the further advantage of eliminating ground clutter and cloud echoes which are usually present in a radar-only system.

The coding used is a three-pulse reply, the spacing between pulses being controlled by the altitude of the aircraft. Conventional circuits, as shown in Fig. 9, are used to produce the three pulses. Coincident decoding circuits, as shown in Fig. 10, are used on the ground to separate the replies into the desired altitude layers. As replies from different aircraft may partly overlap, pulse-line delay circuits are used in the decoders as a delay line can accept a new signal while carrying a previous signal, thus minimizing any decoder dead time. The width of the pulses in the decoder circuits determines the range of each decoder channel and thus the amount of altitude layer overlap of the system. This is carefully controlled by reshaping the received pulses to definite, controlled width.

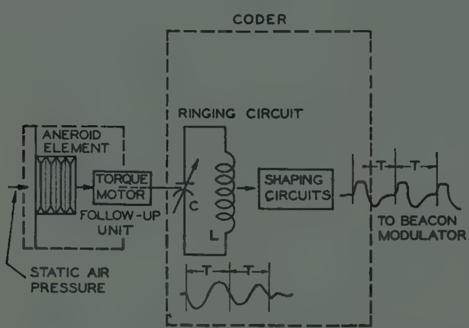

Fig. 9—Teleran transponder altitude-coding system.

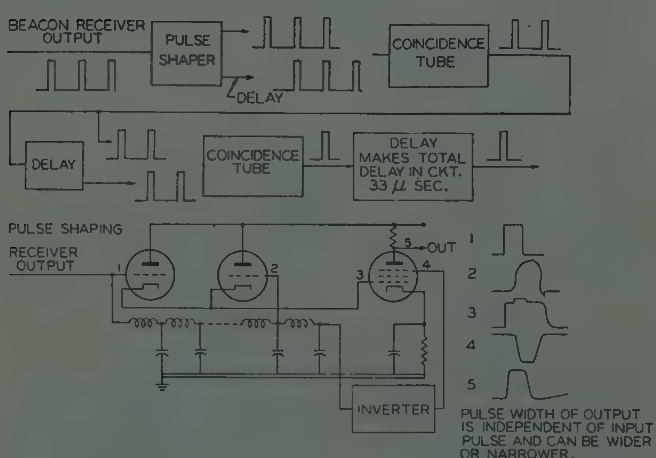

Fig. 10—Decoder block diagram and wave forms; and schematic of pulse-shaping circuit.

6. Altitude Console

Having separated the transponder replies into groups representing altitude layers, the next problem is to superpose a map of the terrain and to provide a means of writing in special instructions such as diagrammatic traffic control patterns. (All of this information must be converted into television video signals for transmission to the aircraft.) The method used is shown in block form

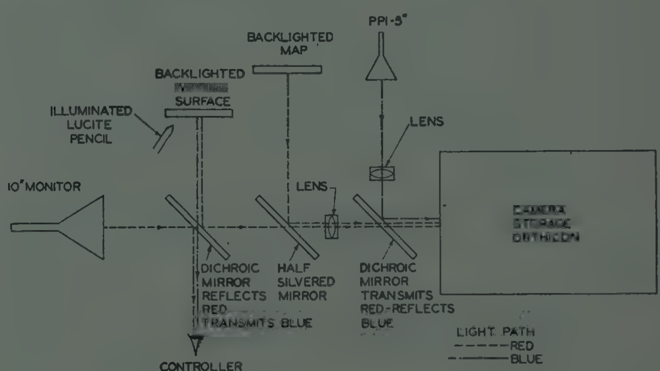

Fig. 11—Diagram of optical mixing system in camera console.

in Fig. 11. Optical mixing of the various sources of information easily produces a high degree of registry of the various sources, without introducing the problem of sweep linearity. Conversion to television video signals is accomplished by using a special storage orthicon tube. The signal from this tube not only produces a bright television-like picture, but its characteristic of storing the radar image for several seconds results in virtual

elimination of the customary flicker or intermittent effect of radar displays.

Optical methods of mixing require excessive space, are somewhat limited as to the number of sources which can be mixed, and are quite inefficient. Since the development of the original teleran equipment, means have been found to produce sweeps with a high degree of linearity. Thus any future developments will employ separate information-source generators and mixing will be done in the video circuits.

7. *Weather Maps*

The weather maps transmitted in the system are separate frames in the multiplexed television transmission. Their video signals are produced by a separate camera. A flying spot camera operating from reflected light (see Fig. 12) is used, with resulting reasonably satisfactory signal-to-noise ratio. The recent development of a 2-inch photomultiplier tube with a gain of 100,000 should give much better performance in any future equipment.

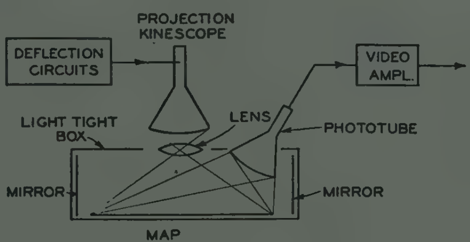

Fig. 12—Weather-map pickup.

8. *The Approach Zone*

The foregoing discussion has described several of the components needed to produce the airways display, which must cover the area within a radius of approximately fifty miles about the radar and possibly as many as twenty altitude layers. In the approach zone, more detailed information is needed. The airport radar station for approach-zone coverage operates with a range of fifteen miles and covers only the lower altitude layers. Multiplexed with the PPI information is a display for the final approach or glide path.

The final approach display is developed from the GCA radar. As is well known, this radar has flat beams scanning in azimuth and elevation over a sufficiently wide angle to cover normal deviations of the aircraft from the glide path. The information from the azimuth scanning antenna is used to develop a sector PPI display with a scale expanded three times in the direction perpendicular to the runway so that the pilot can note more readily his horizontal deviations from the glide path (see Fig. 13). The display shows the airport at the top of the picture with the ground projection of the glide path as a vertical line.

During the elevation antenna scan, the display sweep is vertical and its starting point near the top of the display is tied in to the angular position of the vertical scanning antenna. When a response is received, the output from a blocking oscillator triggered by the response is applied to the horizontal deflection circuits to form a right and left horizontal line on alternate sweeps. If the response is received when the elevation of the antenna corresponds to the proper glide-path angle, showing that the aircraft is at the correct altitude, the starting point of the high-speed vertical sweep of the display is so located as to cause the horizontal line to pass through the pip representing the aircraft. As the vertical sweep is a range sweep, the line continues to pass through the pip as the aircraft approaches. But if the aircraft is above or below the correct glide path, response will be received when the vertical antenna is at an elevation above or below the correct one. Since the starting point of the vertical sweep of the display is tied in to the angular position of the vertical antenna, the starting position will be shifted down or up, and the horizontal line will fall below or above the pip. Thus, at all times the horizontal line indicates the aircraft's position above or below the glide path. Visually the extension of the runway and this horizontal line form an up-down-right-left indicator similar to that of low-frequency localizers, but also indicating range information.

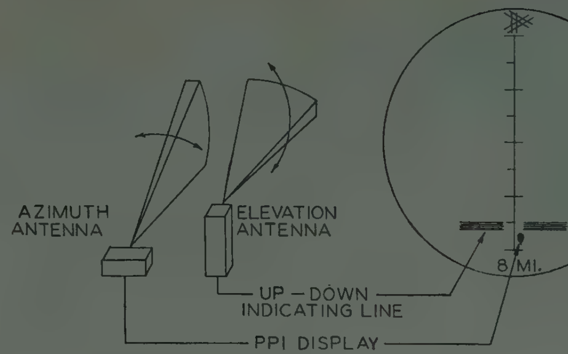

Fig. 13—Diagram of display combining elevation and azimuth information from GCA.

A problem in this display results from the fact that the elevation lines are generated as long as the radar beam illuminates the aircraft. Thus, the width of the total line generated is proportional to the width of the beam. Several schemes for narrowing the line have since been proposed.

9. *Radar Picture Storage*

The storage orthicon[15] was mentioned above. A more recent development in the storage-tube field, the graphechon,[16] is a much more efficient radar-to-television scan converter and storage device. With this tube, two or three radar pulses will produce 30-second storage (many hundred television scans).

In addition, as no optical paths are required, considerable space can be saved and expensive lens systems avoided.

[15] S. V. Forgue, "The storage orthicon and its application to teleran," *RCA Rev.*, pp. 633–650; December, 1947.
[16] L. Pensak, "The graphechon—a picture storage tube," *RCA Rev.*, vol. 10, pp. 59–73; March, 1949.

10. Types of Scans

During the course of the teleran development, several system problems requiring considerable study appeared, among them the selection of a type of scan. The advantages of using a television raster to transmit information such as radar data which are derived in R, θ coordinates are chiefly as follows. First, it is necessary to obtain uniform brilliance and this is generally impractical with radial scan. Also, radial scan does not produce uniform definition over the picture area. If equal definition is to obtained, it is necessary to resolve $2\pi r^2$ elements in the case of the radial scan, but only $4r^2$ in a television raster. Thus radial scan would require about 50 per cent greater bandwidth.

Second, radial sweep would necessitate a mechanical rotation for the airborne receiver display equivalent to the antenna scan on the ground, and since three radars having different rates and types of scan are used, a very difficult problem would be presented.

Third, and probably most important, if 20 altitude layers were to be sent cyclically, some storage of the information would be required, as it is only in this way that the picture could be repeated often enough to obtain a bright and flickerless display. Also, as mentioned earlier, storage tubes bring about a reduction in transmission bandwidth. With present types of storage devices, there is no particular advantage to using the same scan in both reading and writing.

11. Definition

The best kinescopes today have a television resolution of about 1,500 lines in the center and 1,000 lines at the edge. The present system uses 360 lines, but plans for the future include a move to higher definition, probably to the RMA standard of 525 lines. In terms of distance on the display, using 525 lines a line represents 1,000 feet on the long range and 300 feet on the short range. Considerably greater sensitivity is provided in the final approach display. A variation of one per cent in the linearity of the television scan results in a displacement error of four lines, though the relative position of nearby aircraft will still be shown within the accuracy of the resolution. Experience indicates that this accuracy is satisfactory.

12. Automatic Volume Control and Side Lobes

To prevent transponder replies to side lobes of the ground radar when the aircraft is close to the station, an automatic volume control decreases the transponder receiver gain so that the main lobe signal produces a relatively constant output from the receiver. The side lobe signals are then too small to be received. This is satisfactory for a single station, but if two or more ground stations interrogate the same aircraft, replies to the one producing the weaker signal in the aircraft may be lost.

Omnidirectional pulse transmitted by the ground radar station before each directional radar pulse could set an instantaneous automatic-volume-control level in the transponder. If this level were to last only a few microseconds, it would adequately prevent side lobe reception (the side lobe signals being weak compared to the omnipulse), yet would permit reply to a second radar station. It is assumed that the pulses of the second station would not be synchronous with those of the first, except by random coincidence.

Results

During flight tests with the experimental equipment, the following results were observed:

A. Television transmission of navigational data, ground-to-air, was shown to be technically feasible.

B. The combination of radar information (transponder replies) with navigational information into a composite picture for television transmission was demonstrated.

C. The appearance of radar pips having teardrop shape (due to the storage in the storage orthicon) showed that no fundamental obstacle exists which will prevent the indication of flight paths (past) and approximate speeds of all aircraft in the picture.

D. Self-identification by means of a radial line was established as one practicable technique for indicating to the pilot his identity in the picture.

E. Altitude decoding using the pulse-spacing technique was experimentally consistent to a precision of better than 500 feet.

F. A pictorial situation display for final approach was developed from the fundamental data produced by precision-beam (GCA) radar equipment. This display was of high accuracy in the azimuth sense and of usable accuracy in the elevation sense.

Conclusions

In view of the foregoing results, it appears that the combining of radar and television techniques is capable of producing satisfactory pictorial situation displays on the ground and in aircraft, and, in fact, is a method of considerable promise. Among the further developments needed are the design and location of airborne antennas so that pictorial reception will be reliable on the transmission frequency ultimately selected and at all aircraft altitudes. In fact, the broad problem of propagation, antenna design, and multiplexing of services requires careful study from the viewpoint of the over-all air navigation system, of which pictorial display is to be a part.

In parallel with technical developments there should be a psychological evaluation of the pictorial technique. Whereas the teleran tests showed conclusively that pictorial situation displays offer unique and convenient services to ground personnel and to pilots, the authors made no attempt to quantitatively evaluate pictorial display or to ascertain the optimum content and form of such displays. With regard to these factors, a quantitative and somewhat detailed investigation by psychologists and operating personnel would be of great value.

A Theory of Radio Scattering in the Troposphere*

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Summary—**The theory of scattering by a turbulent medium is applied to scattering of radio waves in the troposphere. In the region below the horizon of the transmitter, energy is received (1) by diffraction round the curved surface of the earth (modified as appropriate by atmospheric refraction), and (2) by scattering from turbulence in the region of high field strength above the horizon. At distances beyond the horizon that are not too great, we may think of (1) as giving the mean signal received, and (2) as giving the fading. However, contribution (2) usually decreases with distance more slowly than contribution (1). Beyond a certain distance, therefore, contribution (2) becomes predominant and the mean signal is no longer given by (1). (See Fig. 3.) Values of the scale of turbulence and of the departure of refractive index from mean expected on meteorological grounds are fully adequate to explain the scattered field strengths observed experimentally.**

Introduction

ALTHOUGH THE primary object of the experiments made in the Caribbean Sea[1] in 1945 was to explore the radio consequences of the evaporation-duct that exists at the ocean surface, an important and highly interesting by-product was the discovery that, at any rate under some circumstances, field strength well beyond the horizon decreases with distance more slowly than could be explained on any existing theory.[2] This phenomenon was experienced on a wavelength of 9 cm, but not on a wavelength of 3 cm, where, however, the effect of the evaporation duct was much more marked. It seemed quite clear that the unexpectedly high field strengths obtained at long range on 9 cm were not due to duct propagation, and, on account of the rather violent fading associated with them, it was suggested that a scattering mechanism was involved. Similar results have been obtained in overland transmission in Arizona on various centimeter wavelengths,[3] and what would appear to be the same phenomenon also plays an important role in meter-wave broadcasting.[4] It is the object of this paper to offer an explanation of these observations on the assumption that scattering by variations in the refractive index of the atmosphere is the cause of the phenomenon.

Section I outlines the relevant meteorological facts about turbulent motion in the atmosphere, including the relatively slow, large-scale fluctuations that occur under calm, stable conditions. Section II recasts for radio purposes the theory of scattering by a turbid medium that has been developed by Pekeris[5] in connection with the propagation of sound in water. The aspects of Section II required for practical application (including approximate formulas) are set out in Section III, and an elementary interpretation of these formulas is given in Section IV. The application of the basic scattering theory to communication between directional antennas is described in Section V, and the results are used to compare the theory with observations (particularly the Caribbean observations) in Section VI. In Sections VI and VII it is emphasized that atmospheric scattering or accidental refraction is not only the likely cause of high mean field strengths at long distance in the absence of marked superrefraction, but in all probability is also a main cause of fading at all ranges, and this point is elaborated in Section VII by a calculation of fading time on the basis of the Doppler principle.

I. Atmospheric Turbulence

The atmosphere is an inhomogeneous medium, although mean values of refractive index usually have some horizontal homogeneity. The inhomogeneities are produced and supported by turbulent motion. This section presents a qualitative discussion followed by a mathematical description of the characteristics of turbulence which are pertinent to the scattering of radio waves. Finally the magnitudes of the required parameters are indicated on the basis of available data.

Turbulence may be defined[6] as an irregular motion which in general makes its appearance in fluids, gaseous or liquid, when they flow past solid surfaces, when neighboring streams of the same fluid flow past or over one another, or when thermal instability is present. While the air has a mean speed and a mean direction which are reasonably constant for periods of hours, the instantaneous speed and direction at a particular point may differ widely from the mean values. There is no clear idea of how or why turbulence arises, or of the exact nature of the eddies which form in a fluid in turbulent flow, but something is known of the conditions which must be satisfied if the fluid is to flow without

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[3] J. P. Day and L. G. Trolese, "Propagation of short radio waves over desert terrain," Proc. I.R.E., vol. 38, pp. 165–175; February, 1950.

[4] K. A. Norton, "Advances in Electronics," vol. 1, pp. 392–397; Academic Press, New York, N. Y.; 1948.

[5] C. L. Pekeris, "Note on scattering in an inhomogeneous medium," *Phys. Rev.*, vol. 71, p. 268; February, 1947.

[6] D. Brunt, "Physical and Dynamical Meteorology," Cambridge Press, Cambridge, Mass., 1941.

turbulence (laminar flow), and some information has been accumulated concerning the magnitude of eddy velocities in certain cases.

The local variations of velocity in a fluid are associated with, and are presumably due to, the variations of static pressure which travel downstream with the mean velocity of the stream. The eddy which becomes visible as a dimple in the surface of a stream of water travels in this manner and at the same time it appears to be a simple rotational circulation, the motion being essentially two-dimensional. When a current of air moves over uneven ground we might be tempted to think of the eddies which form in it as cylindrical eddies having their axes in the horizontal plane perpendicular to the direction of the mean wind. Simultaneous records of wind speed and direction show that this is not the case. The results of investigations made under conditions of zero temperature lapse rate with height by Schmidt[7] and Scrase[8] indicate that the mean-square fluctuations of wind speed are approximately equal for the three coordinate components. It is usual to define turbulent velocity at a point as the difference between the instantaneous velocity at the point and the slowly varying mean velocity of the stream, and the intensity of turbulence as the ratio of turbulent velocity to mean velocity. It is found from the same investigations that (1) the intensity of turbulence may be as large as 2/5, with root-mean-square values of the order of 1/10 or 1/20; (2) that the intensity is essentially independent of mean wind speed above about 5 meters per second; and (3) the turbulent velocity is Gaussianly distributed. Thus turbulent velocities occurring in the atmosphere will vary from a few tens of meters per second down to a few centimeters per second.

The contribution to turbulence made by thermal conditions may be estimated from some work performed at the University of Texas.[9] Continuous records of temperature in the lower atmosphere show standard deviations from the mean of instantaneous temperatures of the order of one degree centigrade. The variation of the deviation with thermal conditions sampled seems to be from about 1.2° C under stable situations to 0.7°C for unstable conditions. The time constant of the fluctuations is of the order of minutes for stable and less than a second for unstable conditions. A better estimate of the time constant for unstable conditions was obtained by the use of a hot wire anemometer whose output was examined with a frequency meter. The observed cutoff frequency of 100 cps indicates a time constant of the turbulent fluctuations of the order of one hundredth of a second.

The concept of scale of turbulence is important in this presentation. The scale of turbulence is a quantity which has the dimension length and which is associated with the size of an eddy. It may be thought of as the average size of eddies.[10] An eddy must be considered as any disturbance of the smooth flow. The description of turbulence in terms of intensity and scale resembles the description of the molecular motion of a gas by temperature and free path. In order to obtain mathematical expressions for scale and intensity, consider temperature T as a function of time t, consisting of a mean value $\overline{T}$ and an instantaneous deviation from the mean T', thus

$$T = \overline{T} + T'. \tag{1}$$

The intensity of turbulence is proportional to the ratio of the root mean square of T' to the value $\overline{T}$.

Records of temperature as a function of time show random variations, although there is some short period over which the instantaneous values are correlated. It is this characteristic short-period correlation that the scale of turbulence attempts to describe. The correlation of the temperature at time t with the temperature at time $t+\partial$ may be written

$$R(\partial) = \frac{\overline{T_t' T_{t+\partial}'}}{\overline{T'^2}}. \tag{1a}$$

This is a function of the time interval ∂ which decreases from unity (perfect correlation) for zero time interval to zero (no correlation) for sufficiently large time intervals. As a simple first approach to the magnitude of the scale encountered in the atmosphere we might convert the time constants into correlation distances by means of the wind speed factor. If R falls to zero and remains zero, a scale of turbulence may be defined

$$l = \overline{U} \int_0^\infty R(\partial) d\partial \tag{1b}$$

in which $\overline{U}$ is the mean wind velocity. This yields scales varying from about 10 meters under stable conditions to 10 cm under unstable conditions. Values of the scale are available from the results of the experiments quoted above; (1) Scrase found scales ranging from two to ten meters, and (2) the University of Texas temperature observations indicate scales ranging from about three meters in stable conditions down to just under one meter for unstable conditions. The hot wire anemometer with its considerably smaller time lag provides a lower limit for the scale of turbulence of the order of 10 cm.

The position is therefore that experiments have shown the time constants of the turbulent fluctuations vary from a small fraction of a second to several minutes; that the intensity is Gaussianly distributed with a value which has been observed to be as large as 2/5; that the

[7] W. Schmidt, "Turbulence near the ground," *Jour. Roy. Aero. Soc.*, vol. 39, pp. 355–376; May, 1935.

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[9] J. R. Gerhardt and W. E. Gordon, "Microtemperature fluctuations," *Jour. Met.*, vol. 5, p. 197–203; October, 1948.

[10] G. I. Taylor, "Statistical theory of turbulence," *Proc. Roy. Soc.* London., A 151, p. 421; A 156, p. 307; A 157, p. 540; 1935.

size of the eddies may vary from about 10 cm to 10 meters.

The indicated turbulent nature of the atmosphere permits an examination of the fluctuations of the index of refraction. An estimate of this fluctuation can be obtained from the measured values of the standard deviation from the mean of the instantaneous temperature. Starting with Debye's[11] expression for radio refractive index in terms of temperature, pressure, and moisture, and inserting mean values appropriate for summer conditions in the temperate zones (300°A, 20 mb water vapor, 1,000 mb total pressure) the change in index Δn in terms of changes of temperature ΔT, vapor pressure Δe, and pressure Δp is found to be

$$\Delta n 10^6 \doteqdot 1.4\Delta T + 4.2\Delta e + 0.26\Delta p. \tag{1c}$$

The application of the adiabatic law, a good approximation for eddy motion in the atmosphere, leads to

$$\Delta n 10^6 \doteqdot 2\Delta T. \tag{1d}$$

For the data considered, this corresponds to a standard deviation from the mean of 2 M units.

The atmosphere may therefore be pictured near ground level as subject to accidental fluctuations in refractive index of the order of 1 M unit. These fluctuations are autocorrelated only over distances of the order of l, which varies from 10 cm in unstable conditions to 10 meters in stable conditions. The fluctuations are associated with random motion of the atmosphere with velocities which vary from a few tens of meters per second in turbulent conditions to a few centimeters per second in calm conditions. However, as we go up in the atmosphere we must expect the magnitude of the fluctuations to change and probably to decrease, and the same is no doubt true for the value of the scale l of turbulence.

II. Autocorrelation Analysis of Radio Scattering

Scattering of waves by a turbulent medium is a phenomenon of great importance in connection with the propagation of sound in water, and the problem has been considered with this application in mind by at least two authors.[5,12] The viewpoint which we shall adopt for scattering of radio waves by a turbulent atmosphere is that outlined by Pekeris[5] in connection with sound.

Let ϵ be the average capacitivity (permitivity, dielectric constant) of the atmosphere in a certain region, and let $(\Delta\epsilon)$ be the departure of the capacitivity from its average value at a point P. Let $(\Delta\epsilon)'$ be the departure at a neighboring point P'. Then the variation $(\Delta\epsilon)$ at P is not completely correlated with the variation $(\Delta\epsilon)'$ at P' unless P coincides with P'. As P departs from P', the degree of correlation decreases and at no great distance becomes negligible. The distance PP' at which correlation begins to disappear is essentially the same as the scale of turbulence as defined by Taylor.[10] Define the mean-square departure of the capacitivity from average in a certain volume v as

$$\overline{(\Delta\epsilon)^2} = \frac{1}{v}\int_v |\Delta\epsilon|^2 dv. \tag{2}$$

Then define the autocorrelation function of capacitivity as

$$\rho = \frac{1}{v\overline{(\Delta\epsilon)^2}}\int_v (\Delta\epsilon)(\Delta\epsilon)'^* dv. \tag{2a}$$

The asterisk denotes complex conjugate and assumes that a complex capacitivity is used to take account of losses in the medium if they are important. ρ is a function of the position of P with respect to P'. Its value tends to unity as PP' tends to zero, and to zero as PP' tends to infinity.

As described in the previous section, turbulence in the atmosphere at the height in which we shall be primarily interested may be regarded as isotropic. This means that the autocorrelation function defined by (2a) may be regarded as independent of the direction of PP' and dependent only on the magnitude of PP'. It is quite common[10] to take the autocorrelation function as

$$\rho = \exp(-r/l) \tag{2b}$$

where $r = PP'$ and l is the scale of turbulence, and we shall use this function in detailed work.

If the transmitter and receiver with which we are concerned are omnidirectional, scattering is in general important from nearly the whole of the atmosphere above the horizons of both transmitter and receiver. However, in practice, both transmitter and receiver usually have some directivity, and scattering is then important only in the region of atmosphere where the transmitting and receiving beams overlap. The important scattering volume may be further restricted, if energy is radiated in short pulses rather than continuously. We are thus usually interested in any particular case in scattering from a fairly restricted region of the atmosphere.

We shall be assuming for lack of detailed information that such quantities as the scale of turbulence are uniform throughout the important scattering volume. Strictly speaking, however, some variation of these quantities throughout the scattering volume should be taken into account. This of course would be done by dividing up the scattering volume into elements of volume and integrating. If this is done, it is important to notice that an element of volume in this context must not be too small. Its linear dimensions must be large compared with the scale of turbulence. An element of

[11] P. Debye, "Polar Molecules," Chem. Cat. Co., New York, N. Y.; 1929.

[12] P. G. Bergman, "Propagation of radiation in a medium with random inhomogeneities," *Phys. Rev.*, vol. 70, pp. 486–492; October, 1946.

volume in this sense is the volume v in equation (2a). The element of volume dv in (2a), on the other hand, has linear dimensions small compared with the scale of turbulence, and compared with the wavelength: dv in (2a) is the element of volume used in studying the anatomy of turbulence. We now proceed to consider the scattering from a macroscopic element of volume v regarded as the sum of many microscopic elements of volume dv.

Let the point P of v be at distance R_0 from the transmitter and R from the receiver. Let the electric field at P due to the transmitter be

$$E_0 \exp\{j(\omega t - kR_0)\}. \tag{2c}$$

We suppose that the variations of E_0 in magnitude and direction throughout v may be neglected. We also suppose that multiple scattering may be neglected so that (2c) is the total field at P. Under the influence of the field (2c) an element of volume dv at P, where the departure of capacitivity from average is $(\Delta\epsilon)$, becomes a dipole of moment

$$dv\Delta\epsilon E_0 \exp\{j(\omega t - kR_0)\}. \tag{2d}$$

The polarization (Hertzian) potential produced by this dipole at the receiver is

$$\frac{dv\Delta\epsilon E_0 \exp\{j(\omega t - kR_0)\}}{4\pi\epsilon}\,\frac{\exp(-jkR)}{R}. \tag{2e}$$

The complete polarization potential at the receiver due to scattering from the volume v is therefore

$$\Pi = (E_0/4\pi R)\int_v (\Delta\epsilon/\epsilon)\exp[j\{\omega t - k(R_0+R)\}]dv, \tag{2f}$$

if we neglect variations of R in the magnitudes of contributions from different parts of v, but not in the phases. In terms of Π the scattered electromagnetic field at the receiver may be taken as

$$E = k^2\Pi \sin \mathrm{X} \tag{2g-1}$$

$$H = YE, \tag{2g-2}$$

where Y is the mean characteristic admittance of the atmosphere, and X is the angle between the direction of E_0 in v and the direction from v to the receiver. Substituting from (2f) into (2g-1) and (2g-2) we obtain for the scattered electromagnetic field at the receiver

$$E = (k^2E_0 \sin \mathrm{X})/(4\pi R)\int_v (\Delta\epsilon/\epsilon) \cdot\exp[j\{\omega t - k(R_0+R)\}]dv \tag{2h-1}$$

$$H = (Yk^2E_0 \sin \mathrm{X})/(4\pi R)\int_v (\Delta\epsilon/\epsilon) \cdot[\exp j\{\omega t - k(R_0+R)\}]dv. \tag{2h-2}$$

The complex power-density at the receiver due to scattering in v is therefore

$$\tfrac{1}{2}EH^* = \tfrac{1}{2}Y^*E_0^2\{(k^2\sin \mathrm{X})/(4\pi R)\}^2 I, \tag{2i}$$

where

$$I = \int_v\int_v (\Delta\epsilon/\epsilon)(\Delta\epsilon/\epsilon)'^* \cdot\exp[-jk\{(R_0-R_0')+(R-R')\}]dvdv', \tag{2j}$$

primed and unprimed symbols referring to two different points P' and P of v. The actual power density at the receiver is the real part of $\frac{1}{2}EH^*$, and the power scattered by v towards the receiver measured per unit solid angle is the real part of $\frac{1}{2}EH^*$ multiplied by R^2. Moreover, $\frac{1}{2}Y^*E_0^2$ in (2i) is the power density incident upon v. Hence (2i) implies that the ratio of the power scattered by v towards the receiver per unit solid angle to the power-density incident upon v is

$$\{(k^2\sin \mathrm{X})/(4\pi)\}^2 \tag{2k}$$

times the real part of I, defined by (2j).

To evaluate I we make the following change in (2j). At present the co-ordinates of dv at P and of dv' at P' are both measured from an origin o, and either of the two volume-integrations could be carried out first. Let us now regard dv' as the inner integration and let the co-ordinates of P be measured relative to P' instead of o. This makes no formal change in (2j), which may be rewritten

$$I = \int_v\left[\int_v (\Delta\epsilon/\epsilon)(\Delta\epsilon/\epsilon)'^* dv'\right] \cdot\exp[-jk\{(R_0-R_0')+(R-R')\}]dv.$$

But, from (2a),

$$\rho = \frac{1}{v\overline{(\Delta\epsilon/\epsilon)^2}}\int_v (\Delta\epsilon/\epsilon)(\Delta\epsilon/\epsilon)'^* dv'.$$

Hence

$$I = v\overline{(\Delta\epsilon/\epsilon)^2}\int_v \rho\exp[-jk\{(R_0-R_0')+(R-R')\}]dv. \tag{2l}$$

To proceed further we shall need to insert a value for the autocorrelation function ρ and also to transform the index of the exponential.

In (2l) $R_0 - R_0'$ is the excess of the distance from dv to the transmitter over the distance from the origin to the transmitter, while $R - R'$ is the same quantity for the receiver. We shall now employ spherical polar co-ordinates (r, θ, ϕ) with the same origin and with the axis $\theta = 0$ in the direction from transmitter to v. Let the position vector of dv be

$$r = r(\sin\theta\cos\phi, \sin\theta\sin\phi, \cos\theta), \tag{2m}$$

and the position vector of the receiver be

$$R = R(\sin\Theta\cos\Phi, \sin\Theta\cos\Phi, \cos\Phi). \tag{2n}$$

Then

$$R_0 - R_0' = r\cos\theta \tag{2o-1}$$

$$R - R' = r\{\cos\theta\cos\Theta + \sin\theta\sin\Theta\cos(\phi-\Phi)\}. \tag{2o-2}$$

Hence

$$
\begin{aligned}
(R_0 - R_0') + (R - R') &= r\{1 + \cos\Theta\cos\theta + \sin\Theta\sin\theta\cos(\phi - \Phi)\} \\
&= 2r\sin\tfrac{1}{2}\Theta\{\sin\tfrac{1}{2}\Theta\cos\theta \\
&\qquad - \cos\tfrac{1}{2}\Theta\sin\theta\cos(\phi - \Phi)\} \\
&= 2r\sin\tfrac{1}{2}\Theta\{\cos\tfrac{1}{2}(\Theta - \pi)\cos\theta \\
&\qquad + \sin\tfrac{1}{2}(\Theta - \pi)\sin\theta\cos(\phi - \Phi)\} \\
&= 2r\sin\tfrac{1}{2}\Theta\cos\psi \qquad (2p)
\end{aligned}
$$

where ψ is the angle between the direction $\{\frac{1}{2}(\Theta-\pi), \Phi\}$ and the direction (θ, ϕ).

Substitute from (2p) into (2l), replace dv by $r^2 dr d\Omega$ ($d\Omega$ being an element of solid angle) and assume that ρ is a function of r only, corresponding to isotropic turbulence. We then have

$$I = v\overline{(\Delta\epsilon/\epsilon)^2}\int \rho r^2 dr \int \exp\{-j(2k\sin\tfrac{1}{2}\Theta)r\cos\psi\}d\Omega. \qquad (2q)$$

The radial integration may be taken from zero to infinity since $\rho \to 0$ as $r \to \infty$, and the angular integration is to be taken over all directions. This angular integration is simply that corresponding to a uniform angular spectrum of plane waves cophased at $r=0$ and having propagation constant $2k\sin\frac{1}{2}\Theta$. This corresponds to an isotropic spherical wave having the same propagation-constant. The value of the angular integral in (2q) is therefore

$$4\pi j\frac{\exp\{-j(2k\sin\frac{1}{2}\Theta)r\}}{(2k\sin\frac{1}{2}\Theta)r}, \qquad (2r)$$

the numerical factor following from the behavior for large r. We therefore deduce that

$$
\begin{aligned}
I &= 4\pi j\frac{v\overline{(\Delta\epsilon/\epsilon)^2}}{2k\sin\frac{1}{2}\Theta}\int_0^\infty \rho\exp\{-j(2k\sin\tfrac{1}{2}\Theta)r\}r dr \\
&= 4\pi j\frac{v\overline{(\Delta\epsilon/\epsilon)^2}}{2k\sin\frac{1}{2}\Theta}\frac{1}{\{(1/l) + j(2k\sin\frac{1}{2}\Theta)\}^2} \qquad (2s)
\end{aligned}
$$

on inserting the value (2b) for ρ and carrying out the radial integration. The real part of I is

$$\frac{8\pi v\overline{(\Delta\epsilon/\epsilon)^2}l^3}{\{1 + (2kl\sin\frac{1}{2}\Theta)^2\}^2}. \qquad (2t)$$

With this value for the real part of I, the statement made in connection with (2k) reads as follows. The ratio of the power scattered by v toward the receiver per unit solid angle to the power density incident upon v is

$$\left\{\frac{k^2\sin X}{4\pi}\right\}^2\frac{8\pi v\overline{(\Delta\epsilon/\epsilon)^2}l^3}{\{1 + (2kl\sin\frac{1}{2}\Theta)^2\}^2}. \qquad (2u)$$

For scattering in the direction making an angle Θ with the direction of incidence and an angle X with the direction of the incident electric field, let us define $\sigma(\Theta, X)$ as the scattered power measured

(i) per unit solid angle
(ii) per unit incident power density
(iii) per unit macroscopic element of volume.

Putting $v=1$ in (2u), and also replacing k by 2π divided by the mean wavelength λ in the medium, we deduce that

$$\sigma(\Theta, X) = \frac{\overline{(\Delta\epsilon/\epsilon)^2}(2\pi l/\lambda)^3\sin^2 X}{\lambda[1 + \{(4\pi l/\lambda)\sin\frac{1}{2}\Theta\}^2]^2}. \qquad (2v)$$

This important result differs from that obtained by Pekeris[5] for sound only in the respects in which one would expect a vector wave to differ from a scalar wave. What we have deduced is the energy scattered in any direction by a turbulent medium in which the scale of turbulence is l and the mean-square fractional deviation of dielectric constant from average is $\overline{(\Delta\epsilon/\epsilon)^2}$

III. Approximate Formulas for Scattering by Turbulence

The general formula (2v) for scattering by turbulence is subject to various simplifications under appropriate circumstances. For example, in forward or backward scattering, or indeed for scattering in any direction at right angles to the incident electric field, $\sin^2 X$ in (2v) may be omitted since it is unity. On the other hand, scattering parallel to the direction of the incident electric field is negligible since X is then zero. Moreover, in many applications it will be possible to assume that the scale of turbulence is either small or large in comparison with the wavelength and so to simplify (2v).

If the scale of turbulence is small compared with $(\lambda/2\pi)$, we may neglect to term $\{(4\pi l/\lambda)\sin\frac{1}{2}\Theta\}^2$ in the denominator of (2v) in comparison with unity, thereby obtaining

$$\sigma(\Theta, X) = (1/\lambda)\overline{(\Delta\epsilon/\epsilon)^2}(2\pi l/\lambda)^3\sin^2 X. \qquad (3)$$

If the scale of turbulence is large compared with $\lambda(2\pi)$, we cannot neglect $\{(4\pi l/\lambda)\sin\frac{1}{2}\Theta\}^2$ in comparison with unity except for small values of Θ. The denominator of (2v) implies that, for large-scale turbulence, scattering takes place mainly in a beam directed forwards. Maximum scattering takes place in the direction $\Theta=0$ and the semi-angle of the beam is given by

$$(4\pi l/\lambda)\sin\tfrac{1}{2}\Theta \doteqdot 1. \qquad (3a)$$

Since the beam angle is small when $l \gg \lambda/(2\pi)$, (3a) becomes

$$\Theta \doteqdot \lambda/(2\pi l). \qquad (3b)$$

Most of the scattering by large-scale turbulence therefore takes place within the angle $\lambda/(2\pi l)$ of the forward direction.

For scattering in the forward direction we put $\Theta=0$, $X=\frac{1}{2}\pi$ in (2v) and obtain

$$\sigma(0, \tfrac{1}{2}\pi) = (1/\lambda)\overline{(\Delta\epsilon/\epsilon)^2}(2\pi l/\lambda)^3. \qquad (3c)$$

This formula for forward scattering applies no matter what may be the relation of the scale of turbulence to the wavelength. For other than forward scattering (3c) only requires the modified by the factor $\sin^2 X$ for small-scale turbulence in accordance with (3). But for large-scale turbulence (3c) could only be applied within the angle (3b) of the forward direction; outside this angle we would have to neglect the 1 in the denomination of (2v) in comparison with the $\{(4\pi l/\lambda) \sin \frac{1}{2}\Theta\}^2$, thereby obtaining

$$\sigma(\Theta, X) = \frac{1}{32\pi l}\overline{(\Delta\epsilon/\epsilon)^2}\frac{\sin^2 X}{\sin^4 \frac{1}{2}\Theta}. \tag{3d}$$

In back scattering by large-scale turbulence we put $\Theta = \pi$, $X = \frac{1}{2}\pi$ in (3d) obtaining

$$\sigma(\pi, \tfrac{1}{2}\pi) = \frac{1}{32\pi l}\overline{(\Delta\epsilon/\epsilon)^2}. \tag{3e}$$

The position therefore is that for scattering by a macroscopic element of volume v of a turbulent atmosphere in which $\overline{(\Delta\epsilon/\epsilon)^2}$ is the mean-square fractional deviation of dielectric constant and l is the scale of turbulence, the ratio of the scatter power per unit solid angle in the forward direction to the incident power density is (3c) regardless of the numerical value of $2\pi l/\lambda$. Moreover the same formula applies to back scattering when $2\pi l/\lambda$ is small, but when it is large we must use (3e). For large values of $2\pi l/\lambda$, scattering is mainly confined to directions within an angle $\lambda/(2\pi l)$ of the forward direction.

IV. Elementary Treatment of Scattering by Turbulence

The autocorrelation method has been used for arriving at suitable formulas for scattering of radio waves in a turbulent atmosphere because of the closeness with which the basic assumptions of this method follow modern views concerning the nature of turbulence. With a cruder description of a turbulent medium it is possible, however, to arrive at essentially the same formulas with much less trouble.

Let us think of a turbulent medium as one which contains a large number of spherical blobs. Let ϵ be the mean capacitivity of the medium and $(\Delta\epsilon)$ the excess capacitivity of a typical blob. Let l be the radius of a typical blob. To ensure that the variation of capacitivity along a line drawn through the radius is reasonably random, it would be necessary for the blobs to be packed fairly closely together so that the number per unit volume would be of the order of $1/l^3$. With this model of a turbulent medium, let us calculate the scattering to be expected from a macroscopic element of volume v whose linear dimensions are large compared with l.

Let us consider first the case of small-scale turbulence, taking l small compared with $\lambda/(2\pi)$. Each blob then scatters like an elementary dipole oriented along the incident electric field. Let X be an angle measured from this direction, so that scattered power is proportional to $\sin^2 X$. Then elementary arguments show that the ratio of the power scattered by a single blob per unit solid angle to the incident power density is

$$\left(\frac{2\pi}{\lambda}\right)^4 \left\{\frac{\frac{4}{3}\pi l^3\Delta\epsilon}{4\pi\epsilon}\right\}^2 \sin^2 X. \tag{4}$$

Taking the number of blobs in a volume v as v/l^3, we obtain for scattering by a macroscopic element of volume

$$\frac{v}{l^3}\left(\frac{2\pi}{\lambda}\right)^4\left(\frac{\frac{4}{3}\pi l^3(\Delta\epsilon)}{4\pi\epsilon}\right)^2 \sin^2 X, \tag{4a}$$

or, on rearrangement,

$$(2\pi/9)(1/\lambda)\overline{(\Delta\epsilon/\epsilon)^2}(2\pi l/\lambda)^3 \sin^2 X. \tag{4b}$$

This differs from (3) only by a numerical factor $2\pi/9$, which could be absorbed by taking a suitable ratio between the radius of the blobs and the scale of turbulence as defined by (2b).

In the same way the formulas for large-scale turbulence developed by the autocorrelation method may be obtained from a model involving closely packed blobs. A blob whose radius l is large compared with the wavelength scatters energy mainly forwards, and the beam angle of the scattered radiation is related to the size of the blob by the usual antenna formulas connecting beam width with aperture width. The beam angle of the radiation scattered by a blob, and therefore also by many randomly located blobs, is of the order of λ/l, in agreement with (3b).

The complete scattering polar diagram given by (2v) for large-scale turbulence may be reproduced either by taking a suitable statistical distribution of blob size or by using a suitable cross-sectional profile for the blobs. In this connection it is interesting to notice a relation between the cross-sectional profile of blobs and the autocorrelation function defined by (2a). The relation follows from the integral in (2l), which, in accordance with (2i), is proportional to the power polar diagram of the scattered radiation, except for the $\sin^2 X$ dipole-factor. The index of the exponential in (2l) represents the phase difference between two paths from transmitter to receiver, one via the point P of v and the other via the point P'. The function of the exponential factor is therefore to ensure that the contributions from different microscopic elements of volume of v are added in the appropriate phase. The integral is in fact precisely what one would write down for the amplitude polar diagram of a blob whose cross-sectional profile of dielectric constant deviation is proportional to the autocorrelation function (2a). We must notice however, that (2i) gives, not the amplitude polar diagram of scattering by v, but the power polar diagram. We thus see that the power polar diagram of scattering by a turbulent medium is the same as the amplitude polar diagram of a single blob whose cross-sectional profile of $\Delta\epsilon$ is proportional to the autocorrelation function of the dielectric con-

stant of the medium. This is a three-dimensional version of a result used by Booker, Ratcliffe, and Shinn[13] in connection with ionospheric propagation.

The upshot is that scattering by a turbulent medium may be quite well described in terms of closely packed blobs whose size is roughly equal to the scale of the turbulence. The blobs would of course have to be thought of as moving with the wind, and in addition having a random motion of the order of magnitude mentioned in Section I. This approach to scattering by turbulence is useful in relating the problem to others of which one has previous experience, such as scattering of microwaves by rain, or scattering of light waves by molecules. Fundamentally however, the approach in terms of the autocorrelation function of the turbulent medium is to be preferred.

V. Application to Beam Communication

Let us consider transmission from a point T to a point R at distance d round the curved surface of the earth by means of beamed antennas pointed more or less at each other as indicated in Fig. 1. It is assumed that there are no ducts and that as far as ordinary refraction is concerned propagation is orthodox. We suppose that both

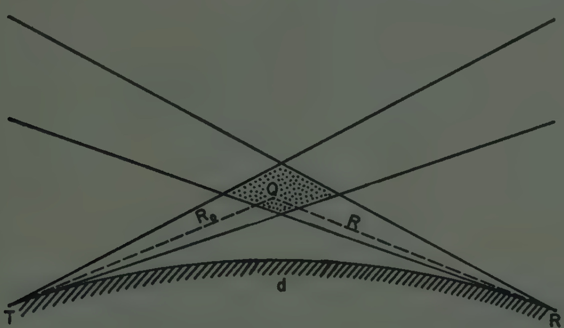

Fig. 1

antennas are pointed horizontally at their respective locations, and that their axes lie in the vertical plane through T and R. The two beams then intersect in a common volume, and it is scattering in this volume that is mainly responsible for the scattered signal received from T at R.

For simplicity, let us suppose that the T and R antennas are identical. Let b be the vertical dimension and b' the horizontal dimension of either aperture (or equivalent aperture), and let the aperture area be $A = bb'$. The linear dimensions of A are supposed large compared with the wavelength λ, so that the beams are narrow. They have solid angle λ^2/A and again

$$G = 4\pi A/\lambda^2, \tag{5}$$

relative to an isotropic radiator. The vertical beam widths of the T and R beams are halved by the presence of the earth. For a smooth earth, we may assume that all the radiated power is concentrated in the half beam width, but for a rough earth, half the power would be scattered more or less isotropically by the earth. We shall take the solid angles of the beams as

$$\Omega = \lambda^2/(2A), \tag{5a}$$

but use the expression (5) for gain.

Consider scattering by a macroscopic element of volume dV at a point Q of the volume common to the T and R beams. Let R_0 and R be the distances of Q from transmitter and receiver, respectively. Let σ (Θ, X) describe the scattering properties of the element dV in accordance with the formula (2v), or one of the approximations thereto given in Section III. If P_0 is the power radiated by T then, allowing for gain, the power density at Q is

$$\frac{P_0}{4\pi R_0^2}\,\frac{4\pi A}{\lambda^2}\cdot \tag{5b}$$

Hence the power scattered per unit solid angle by dV towards R is

$$\frac{P_0}{4\pi R_0^2}\,\frac{4\pi A}{\lambda^2}\,\sigma(\Theta, \mathrm{X})(dV), \tag{5c}$$

and the corresponding power received at R is

$$\frac{P_0}{4\pi R_0^2}\,\frac{4\pi A}{\lambda^2}\,\sigma(\Theta, \mathrm{X})(dV)\,\frac{A}{R^2}\cdot \tag{5d}$$

We obtain the total power P received at R by integrating with respect to dV over the volume of atmosphere common to the T and R beams

$$\frac{P}{P_0} = \frac{A^2}{\lambda^2}\int \frac{\sigma(\Theta, \mathrm{X})}{R_0^2 R^2}\,dV. \tag{5e}$$

Precise evaluation of the integral (5e) over the common volume of the T and R beams is tiresome. The difficulty is reduced however if we can take σ (Θ, X) as a constant given by (3c), so that

$$\frac{P}{P_0} = \frac{A^2\sigma}{\lambda^2}\int \frac{dV}{R_0^2 R^2}\cdot \tag{5f}$$

This simplification requires that turbulence be more or less uniform throughout the scattering volume. For l large compared with $\lambda/(2\pi)$, it is also necessary that the receiver should be within the main scattering beam of the atmosphere. Now the semi-angle of the scattering beam, from (3b), is $\lambda/(2\pi l)$, the horizontal and vertical angles of the T and R beams are λ/b' and $\lambda/2b$, and the angle between the axes of the beams is d/a approximately, a being the radius of the earth. Hence the conditions that the receiver is within the scattering beam are

$$\frac{\lambda}{2\pi l} > \frac{\lambda}{b'} \quad \text{and} \quad \frac{\lambda}{b} + \frac{d}{a}\cdot \tag{5g}$$

[13] H. G. Booker, J. A. Ratcliffe, and D. H. Shinn, "Diffraction from a random screen with applications to ionospheric problems," to be published.

For d appreciably less than $\lambda a/b$, this simply means that the scale of turbulence must be appreciably less than the linear dimensions of the antennas. Let us assume in accordance with (5g) that

$$l < \frac{b'}{2\pi} \quad \text{and} \quad \frac{b/2\pi}{1+(bd/a\lambda)} \tag{5h}$$

and use the formula (5f) for the ratio of scattered power received to power transmitted, with the value (3c) for σ.

Even the remaining integral in (5f) is tiresome to evaluate precisely, on account of the shape of the volume enclosed by the T and R beams. Let us consider

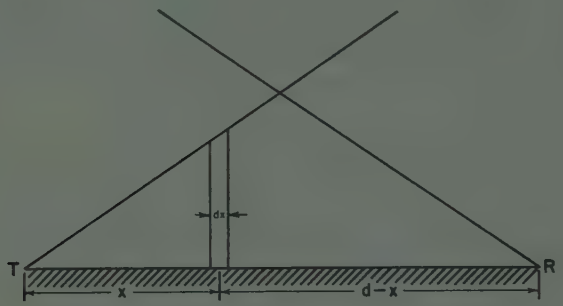

Fig. 2

first the case of a flat earth illustrated in Fig. 2. At distance x from T and $(d\text{-}x)$ from R the cross-sectional area of the scattering volume at right angles to the vertical plane of transmission is $(\lambda^2/2A)x^2$. Hence the integral in (5f) may be taken approximately as

$$2\int_0^{d/2} \frac{(\lambda^2/2A)x^2dx}{x^2(d-x)^2} = \frac{\lambda^2}{A}\int_0^{d/2} \frac{dx}{(d-x)^2}$$
$$= \lambda^2/(Ad). \tag{5i}$$

Substituting into (5f), the ratio of scattered power received to power transmitted becomes

$$P/P_0 = A\sigma/d \tag{5j}$$
$$= \frac{A}{\lambda d}\overline{\left(\frac{\Delta\epsilon}{\epsilon}\right)^2}\left(\frac{2\pi l}{\lambda}\right)^3 \tag{5k}$$

on using the expression (3c) for σ.

Formula (5k) for a flat earth may be applied to a curved earth provided the angle between the axes of the T and R beams is appreciably less than their vertical beam angle, that is, provided

$$\frac{d}{a} < \frac{\lambda}{2b}\cdot \tag{5l}$$

Formula (5k) thus applies up to ranges of the order of $\lambda a/2b$. For ranges appreciably greater than this we may regard the scattering volume as a fairly restricted parallelopiped (see Fig. 1) whose edges in the vertical plane of propagation are of length

$$\frac{\lambda/(2b)}{d/a}\,\frac{d}{2} = \frac{\lambda a}{4b} \tag{5m}$$

and whose edge is the direction normal to this plane is of length $(\lambda/b')\,(d/2)$. The scattering volume is thus

$$\left(\frac{\lambda a}{4b}\right)^2 \frac{\lambda d}{2b'}\,\frac{d}{a} = \frac{\lambda^3 ad^2}{32b^2b'}\cdot \tag{5n}$$

The scattering volume is now sufficiently restricted so that in (5f) we may take

$$R_0 = R = d/2.$$

Hence (5f) becomes

$$\frac{P}{P_0} = \frac{A^2\sigma}{\lambda^2}\left(\frac{2}{d}\right)^4 \int dV \tag{5o}$$

$$= \frac{A^2\sigma}{\lambda^2}\left(\frac{2}{d}\right)^4 \frac{\lambda^3 ad^2}{32b^2b'} \text{ from (5n)}$$
$$= \tfrac{1}{2}\lambda a\sigma b'/d^2. \tag{5p}$$

Using the expression (3c) for σ, we deduce for the ratio of scattered power received to power transmitted

$$\frac{P}{P_0} = \frac{ab'}{2d^2}\overline{\left(\frac{\Delta\epsilon}{\epsilon}\right)^2}\left(\frac{2\pi l}{\lambda}\right)^3, \tag{5q}$$

this formula applying when

$$d > \lambda a/(2b). \tag{5r}$$

Since in (5q) we have used the expression (3c) for σ, the formula is subject to the restrictions (5h) which, under the condition (5r), become

$$l < \frac{b'}{2\pi} \quad \text{and} \quad \frac{\lambda a}{2\pi d}\cdot \tag{5s}$$

The second of these conditions clearly breaks down at sufficiently large distances, and we then have to use the expressions (3) or (3d) for σ instead of (3c). This makes no difference when l is small compared with $\lambda/(2\pi)$ and polarization is horizontal ($X=\frac{1}{2}\pi$ in (3)), and even for vertical polarization the correction is usually negligible. But when l is large compared with $\lambda/(2\pi)$, we must use the expression (3d) for σ. Putting $X=\pi/2$ in (3d) (exact for horizontal polarization, approximate for vertical) and taking Θ as the angle d/a between the axes of the T and R beams, (3d) becomes approximately

$$\sigma = \frac{1}{2\pi l}\overline{\left(\frac{\Delta\epsilon}{\epsilon}\right)^2}\left(\frac{a}{d}\right)^4 \tag{5t}$$

and, using this value of σ in (5p), we obtain

$$\frac{P}{P_0} = \frac{\lambda a^5 b'}{4\pi l d^6}\overline{\left(\frac{\Delta\epsilon}{\epsilon}\right)^2}. \tag{5u}$$

This formula gives the ratio of the scattered power received to the power radiated for ranges appreciably greater than both $\lambda a/(2b)$ and, from (5s), $\lambda a/(2\pi l)$, provided l is significantly greater than $\lambda/(2\pi)$; for l signifi-

cantly less than $\lambda/(2\pi)$ formula (5k) applies for all ranges appreciably greater than $\lambda a/(2b)$ (but not as large as a) regardless of the exact value of l.

Comparing formulas (5k), (5q), and (5u) we see that the scattered energy received decreases inversely proportional to range up to ranges of the order of $\lambda a/(2b)$, then inversely proportional to the square of range up to ranges of the order of $\lambda a/(2\pi l)$. This rate of decrease continues unless l is appreciably greater than $\lambda/(2\pi)$, in which case it becomes inversely proportional to the sixth power of range. This assumes that the scale of turbulence is appreciably less than the vertical dimension of the antennas. If the reverse were true, the transition from formula (5q) to formula (5u) would involve a situation in which the receiver was in the main scattering beam for only part of the complete scattering volume.

It will be noticed that, according both to formulas (5k) and (5q), the scattered energy received increases proportionally to the cube of the scale of turbulence, whereas according to (5u) it decreases inversely proportional to the scale of turbulence. The reason for the decrease in the last case is that scattering is beamed and the receiver is outside the scattering beam, so that further beaming reduces the scattered energy received. For a receiver within the scattering beam however, the scattered energy received increases proportional to the cube of the scale of turbulence, so that a variation of l from 10 cm to 10 meters, as suggested in Section I on meteorological grounds, would cause a 60-db variation in the scattered energy received.

We see that the scattered energy received is inversely proportional to λ^4 according to (5k) but directly proportional to λ according to (5u). This behavior in formula (5k) may be considered as a consequence of the Rayleigh scattering law when l is less than $\lambda/(2\pi)$. But when l is greater than $\lambda/(2\pi)$ it is a consequence of the increased forward beaming of the scattering as the wavelength decreases. This continues (apart from introduction of earth's curvature in (5q)) until the scattering beam is so narrow that the receiver is outside it. Then a further decrease of wavelength, with its consequent increased beaming, causes a decrease of scattered energy received as exhibited by (5u).

All three formulas (5k), (5q), and (5u) for scattered energy received are proportional to the horizontal dimensions of the antenna aperture. Only (5k) is, however, proportional to the vertical dimension. The reason for this is that, at ranges greater than about $\lambda a/(2b)$, the increase in gain corresponding to an increase in b is just compensated by a decrease in the scattering volume (see Fig. 1).

While calculations such as those outlined above are satisfactory for continuous-wave transmissions, some further consideration is necessary when the radiation is modulated, for example, by short pulses. Such a pulse would only illuminate at any one instant a small slice of the scattering volume over which we have integrated, and we have to consider whether scattering from the various parts of the scattering volume would arrive at the receiver at more or less the same time. We may regard the shortest scattering path from T to R as passing along the bottom edge of the transmitting beam and then along the bottom edge of the receiving beam. In the same way, the longest path may be taken to go along the top edges of the beams, and we wish to calculate the difference between the shortest and longest paths. For ranges less than $\lambda a/(2b)$ we may use Fig. 2 and arrive at a path difference $(\lambda/b)^2\,(d/2)$ approximately, while for ranges greater than $\lambda a/(2b)$ we use Fig. 1 and deduce a path difference of approximately $(\lambda/b)d^2/(4a)$. Dividing by c, the velocity of light, we see that modulation whose time constant is shorter than

$$\begin{aligned} &\frac{1}{c}\left(\frac{\lambda}{b}\right)^2\frac{d}{2} \quad d < \lambda a/(2b), \\ &\frac{1}{c}\,\frac{\lambda}{b}\,\frac{d^2}{4a} \quad d > \lambda a/(2b), \end{aligned} \tag{5v}$$

is blurred, so far as reception by scattering is concerned. In particular, pulses of length greater than (5v) are undistorted as a result of the spread of scattering path length.

In a number of practical cases of pulse communication at centimeter wavelengths, the range is sufficiently short for distortion of the pulse by scattered radiation to be unimportant. Moreover, the range is frequently short enough to permit application of formula (5k). This formula therefore emerges as the most important result of this section, and may be modified for practical application as follows. In the first place, the formulas for scattered energy are proportional to $\overline{(\Delta\epsilon/\epsilon)^2}$, and if ΔM is the mean-square deviation from mean of the refractive index measured in M units as used in (1), then

$$\overline{(\Delta\epsilon/\epsilon)^2} = 4.10^{-12}\,(\Delta M)^2. \tag{5w}$$

Moreover, when using formula (5k) (or even (5q)), turbulence enters into the expression for scattered energy through the factors $l^3\overline{(\Delta\epsilon/\epsilon)^2}$, or $l^3\,(\Delta M)^2$. Since (5k) is the formula with which we shall be actively concerned, it will be convenient to measure the degree of turbulence in the atmosphere in terms of the quantity

$$l' = l(\Delta M)^{2/3}. \tag{5x}$$

As described in Section I, ΔM near the earth's surface does not usually differ much from 1 M unit, so that l' may be thought of roughly as the scale of turbulence itself, and might be described as the modified scale of turbulence. In terms of the modified scale of turbulence (5x), the important formula (5k) becomes

$$\frac{P}{P_0} = 4.10^{-12}\,\frac{A}{\lambda d}\left(\frac{2\pi l'}{\lambda}\right)^3. \tag{5y}$$

If we measure the received power P in micromicrowatts, the transmitted power P_0 in kilowatts, the distance d be-

tween transmitter and receiver in kilometers, the area A of the antennas in square meters, the wavelength λ in meters, and the modified scale of turbulence l' in meters, (5y) becomes

$$\frac{P}{P_0} = \frac{4A}{\lambda d}\left(\frac{2\pi l'}{\lambda}\right)^3, \tag{5z}$$

and this formula gives the scattered power received for a wide range of practical cases of beam communication between nearly identical antennas.

VI. Comparison of Theory with Experiments

What has been calculated in the preceding sections is purely the signal received by scattering, and to this must be added the conventional signal that would be received in the absence of turbulence in the atmosphere. At short range the conventional signal is much greater than the scattered signal, so that the conventional signal is the mean signal observed, while the scattering is responsible for fading. The observed signal amplitude would be expected to be more or less normally distributed about the conventional signal amplitude as mean, with a standard deviation given by the scattered signal amplitude calculated above.

What a formula such as (5k) purports to give, therefore, is the variation with distance, etc., of the fading range, suitably defined. Now it will be noticed that, according to (5k), the scattered energy decreases with distance inversely proportional to d. On the other hand the conventional signal energy within the horizon decreases inversely as d^2, apart from interference between a direct wave and one reflected from the earth's surface. Hence the ratio of fading range to mean signal increases as we recede from the transmitter. Beyond the horizon, the conventional signal (except under conditions of marked superrefraction) begins to decrease exponentially with distance, while the fading range only decreases inversely proportional to some power of d in accordance with a formula such as (5k), (5q), or (5u). Thus, a distance is ultimately reached at which the conventional signal is no bigger than the scattered signal. At greater distances, scattered energy provides the main signal received. At these distances observed signal amplitude should be distributed according to the Rayleigh distribution. Moreover, the mean signal will no longer be determined by the conventional calculation omitting turbulence of the atmosphere, but instead will be given by a formula of the type developed in the preceding section. If, therefore, only mean signal is observed as a function of distance, a kink will appear in the curve where the mean signal is no longer determined by the conventional mechanism of propagation, but instead by the phenomenon of scattering, which at shorter range is the primary cause of fading. The situation may be roughly described by saying that fading decreases with increase of distance more slowly than the conventional signal, so that at long range the conventional signal becomes unimportant and one is left merely with the fading.

The slow decrease of scattered energy with increase of distance is illustrated in Fig. 3, which is drawn to correspond to the observations made on a wavelength of 9 cm in the Caribbean Sea and reported by Katzin and co-workers.[1] In these experiments the transmitting and receiving antennas were circular dishes with diameters

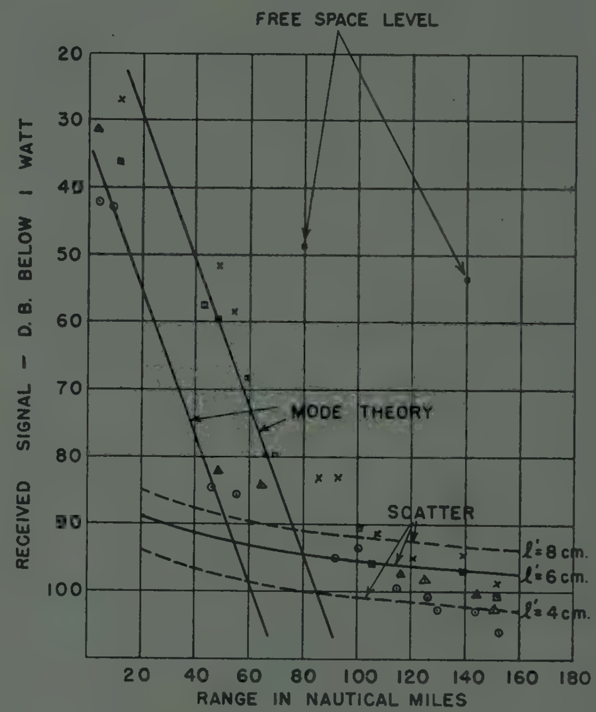

Fig. 3

of 4 feet and 3 feet, respectively, so that the assumption of identical antennas made in Section V is not precisely fulfilled. However, we assume that results would not have been very different if the apertures of both antennas had had horizontal and vertical dimensions of 10 wavelengths. We also take the radius of the earth to be 8,000 kilometers to allow for orthodox atmospheric refraction above the surface duct that was present during the experiment. For these observations, therefore, we have

$$\frac{\lambda a}{2b} = 400 \text{ km}. \tag{6}$$

Since observations were not made at ranges beyond about 275 km, we may use approximate formulas valid for distances appreciably less than $\lambda a/(2b)$. It follows from (5v) that the maximum path difference involved in scattering, even at maximum range, is only about 1 microsecond, so that no marked distortion of the 1-microsecond pulses used in the experiment is to be expected. Moreover, if we assume tentatively that the scale of turbulence is of the order of 10 cm or less, conditions (5h) are satisfied and we may use formula (5k),

or its modified form (5z), for the scattered energy received.

In Fig. 3 two curves marked mode theory represent the variations of field strength with distance as deduced from calculations by Pekeris[2] for the conditions under which the experiments were carried out; the two curves correspond to different heights of transmitter and receiver. The corresponding mean field strengths observed are indicated in Fig. 3 by the experimental points which are taken from Fig. 7 of the paper[1] describing the Caribbean measurements. The agreement between the mode theory and the observations is satisfactory, except at long range. The other three curves in Fig. 3 represent the scattered energy received as a function of distance on the basis of formula (5z) using modified scales of turbulence of 4, 6, and 8 cm. It will be seen that, at ranges beyond those at which conventional theory agrees approximately with the observations, the field strengths received may be interpreted roughly in terms of a uniformly turbulent atmosphere having a modified scale of turbulence of about 6 cm. What the theory predicts is that the curves of mean field strength as a function of distance for the various heights of transmitter and receiver concerned should follow the mode-theory curves in Fig. 3 up to roughly the range where they intersect the unbroken curve for the scattering theory, and that they should then all turn and follow the curve for the scattering theory. It is clear that a theory derived in this way is in much better agreement with the observations than one in which scattering is neglected.

The Caribbean experiments were carried out in an unstable atmosphere, and for such an atmosphere values of 10 cm for l and 1 M unit for ΔM were mentioned in Section I as appropriate near the earth's surface. This figure would give a modified scale of turbulence of 10 cm, somewhat greater than that suggested by the observations reproduced in Fig. 3. It must be remembered, however, that the values quoted in Section I referred to conditions over land, whereas the Caribbean experiments were carried out over sea. Moreover, the modified scale of turbulence is expected to decrease with height above the earth's surface, and we are concerned more with turbulence at a height than with turbulence near the surface.

It will also be noticed in Fig. 3 that the theory of atmospheric scattering seems to predict a decrease of scattered field strength with distance that is too low to agree with the observations. Again, however, it must be remembered that we have assumed in our simple application in Section V of the results of Sections II and III that the modified scale of atmospheric turbulence is independent of height above the earth's surface, whereas in fact it almost certainly decreases with height in most practical cases. Now, as illustrated in Fig. 1, the height of the important scattering volume increases with increase of distance between transmitter and receiver, and an associated decrease of the modified scale of atmospheric turbulence would cause the scattered signal received to decrease more rapidly with increase of range than for a uniformly turbulent atmosphere. It might even be possible from observations of radio scattering as a function of range to draw some deductions about atmospheric turbulence as a function of height.

If our interpretation of the relatively high field strengths observed at long range on the 9-cm wavelength in the Caribbean experiments is correct, formula (5z) should not only give the field strength observed at sufficiently long ranges, but should also give the standard deviation of field strength at shorter ranges. This aspect of the theory could not however be checked from the Caribbean observations as published.[1]

We are of the opinion that many of the existing divergences between observations and conventional theory can be explained along the lines that we have used in connection with the Caribbean experiments. Thus is is reported, both in connection with centimeter-wave communications and in connection with meter-wave broadcasting, that increasing the height of the transmitting antenna often has little or no influence on the field strength received well beyond the horizon. This is what might be expected when the scattered signal exceeds the signal anticipated on conventional theory. Norton[4] reports that, even with a well-mixed atmosphere, the Richmond, Va., frequency-modulation station on a wavelength of 3 meters produces at the Central Radio Propagation Laboratory, Washington, D. C., a field strength some 30 db above what would be expected under orthodox propagation conditions, according to the usual theory of diffraction round the curved surface of the earth. This suggests that, at the range of 98 miles involved in these observations, the scattered energy received exceeds that which would be expected on conventional theory. The scattered energy per unit volume of atmosphere is of course a good deal less at a wavelength of 3 meters than it is at 9 cm (see equation (5k)). But the beam widths involved in broadcasting are so great that the volume of atmosphere contributing to the scattered energy is quite large. The volume concerned is indeed so large that even approximate evaluation of the integral involved in (5f) is by no means easy. A rough calculation shows however that a scattered field strength of the order of magnitude reported by Norton can be explained in terms of a value for the modified scale of turbulence of an order of magnitude that is reasonable from the meteorological standpoint.

In connection with meter-wave broadcasting, it should be noted that there is a possibility of an interesting difference in scattering behavior between horizontal and vertical polarizations. There are probably many occasions on which the scale of turbulence in the atmosphere is appreciably less than the wavelength involved, so that (3) is the appropriate scattering formula. This implies that each macroscopic element of volume scatters uniformly in all directions except for the dipole-factor $\sin^2 X$. With an almost nondirectional receiving antenna, therefore, the region of atmosphere more or

less vertically above the receiver will be of great importance. But for vertical polarization a dipole vertically above the receiver will be end-on to the vertical dipole(s) used for reception, whereas for horizontal polarization the two dipoles are parallel. Consequently rather less scattered energy should be received with vertical polarization than with horizontal. Whether the difference is sufficiently important to affect the spacing of meter-wave broadcasting stations operating in the same frequency channel is doubtful, however.

We conclude that atmospheric scattering due to turbulence is the cause of the slow variation of mean field strength with distance experienced on a wavelength of 9 cm at long range in the Caribbean experiments, and probably also in other cases. Moreover we predict that the same theory which is used for calculating the scattered signal at long distances may also be used in most cases for calculating the fading range at shorter distances.

VII. Speed of Fading

If fading is largely due to scattering in a turbulent atmosphere as suggested above, it should be possible to calculate the speed of fading from the velocities of turbulence quoted in Section I. This is done by the method used by Ratcliffe[14] in connection with ionospheric propagation and depends on an application of the Doppler principle. If a scattering element is moving with velocity v, the scattered radiation differs very slightly in frequency from the incident radiation. Radiation received from the various scattering elements is therefore spread over a narrow band of frequencies, and it is beating between these frequencies that causes fading.

For backward scattering by an element moving in the direction of incidence with velocity v, the fractional Doppler shift in frequency is $(2v/c)$. In forward scattering however, there is no Doppler shift at all, and for scattering through an angle Θ, the fractional Doppler shift frequency is

$$2(v/c)\sin\left(\tfrac{1}{2}\Theta\right). \tag{7}$$

Fading is therefore caused by beating between frequencies which differ by roughly this fraction of the operating frequency f, so that the quasifrequency of fading is

$$2f(v/c)\sin\left(\tfrac{1}{2}\Theta\right) = (2v/\lambda)\sin\left(\tfrac{1}{2}\Theta\right). \tag{7a}$$

The quasiperiod of fading is therefore

$$\frac{\lambda}{2v\sin\left(\tfrac{1}{2}\Theta\right)} = \lambda/(v\Theta) \tag{7b}$$

[14] J. A. Ratcliffe, "Diffraction from the ionosphere and the fading of radio waves," *Nature*, vol. 162, p. 9; 1948.

for scattering through small angles.

For two-directional antennas of beam width Θ facing one another, the greatest angle of scatter that need be considered is Θ so that the shortest fading time is given by interpreting Θ in (7a) as beam width. We see that, for a fixed beam width, fading time is proportional to wavelength. For fixed linear dimensions b of the antennas, however, we have

$$\Theta = \lambda/b \tag{7c}$$

approximately, so that the fading time may be taken as

$$b/v. \tag{7d}$$

This result implies that, for communication between beam antennas of fixed linear dimensions, fading time is independent of frequency, and is of the order of magnitude of the time taken to traverse a distance equal to the linear dimensions of the antennas at a speed equal to the mean velocity of turbulence. The expression (7d) for the fading time is however based on the assumption that the scattering angle is limited by beam width, but if the scale of turbulence l is appreciably greater than the linear dimensions b of the antennas, the angle of scattering would be limited rather by the scattering beam width of the atmosphere given by (3b). We would then use the value (3b) for Θ in (7b) and deduce for the fading time

$$\frac{2\pi l}{v}. \tag{7e}$$

We thus see that the fading time is given by (7d), or (7e) which ever is the longer.

At ranges such that the curvature of the earth is important (d comparable with or greater than $\lambda b/a$; see equations (5q), (5u), and Fig. 1) the angle d/a between the axes of horizontally pointed transmitting and receiving antennas would have to be taken into account, leading to a situation in which fading time is inversely proportional to range when the range is appreciably greater than $\lambda b/a$.

Unfortunately we have not been able to find in the literature enough information on fading time to test the above statements. However, there seems no doubt that the expressions (7d) and (7e) give fading periods of the right order of magnitude. For example, under turbulent conditions, with typical antennas, either b or $2\pi l$ is of the order of a meter and v is of the order of a few meters per second, giving a fading time of rather less than a second. On the other hand, under stable conditions l would be larger and v smaller leading to much slower fading.

Helix Parameters Used in Traveling-Wave-Tube Theory*

R. C. FLETCHER†

Summary—**Helix parameters used in the normal mode solution of the traveling-wave tube are evaluated by comparison with the field equations for a thin electron beam. Corresponding parameters for a thick electron beam are found by finding a thin beam with approximately the same rf admittance.**

Introduction

THE THEORY OF traveling-wave tubes has been treated by two different methods; (1) solution of the field equations[1,2] and (2) expansion in the normal modes of propagation.[3,4] The field solution has the advantage of being directly applicable to a particular physical situation without the introduction of unknown parameters, while the normal mode solution has the advantage of being more generally applicable and more easily manipulatable, but requires the independent evaluation of such parameters as the circuit impedance, the unloaded propagation constant, and the passive mode or "space-charge" parameter. It is the purpose of the present paper to show the equivalence of the two methods, and to use this equivalence to evaluate the parameters appearing in the normal mode solution, for the particular case of an electron beam within a helix.

Equivalence of Methods for a Thin Beam

Let us first consider a thin beam whose breadth is small enough so that the field acting on the electrons is essentially constant. The normal mode solutions obtained by Pierce[3,4] apply only to this case. The more practical situation of a thick beam will be considered later. The normal mode method consists of simultaneously solving two equations, one relating the rf field produced on the circuit by an impressed rf current from the electron stream, and the other relating rf current produced in the electron stream by an impressed rf field from the circuit. Using the following as symbols,

E = rf field acting on the electron beam
q = rf current in the electron beam
Γ = propagation constant. Field quantities vary as $\exp(-\Gamma z)$
Γ_0 = natural propagation constant of the mode which is principally being excited by the electrons
K = circuit impedance of this mode ($=E^2/2\beta^2P$ of Pierce)[3,4]
Q = a parameter which represents the effect of passive modes[3,4]
$\beta_e=\omega/u_0$
ω = impressed frequency
u_0 = dc velocity of the electrons
I_0 = dc current of the electrons
V_0 = dc accelerating voltage
$k=\omega(\mu\epsilon)^{1/2}$,

we can write the circuit equation as

$$E=-\left[\frac{\Gamma^2\Gamma_0K}{\Gamma^2-\Gamma_0^2}+\frac{2jQK\Gamma^2}{\beta_e}\right]q, \tag{1}$$

and the electronic equation as

$$q=\frac{j\beta_e}{(j\beta_e-\Gamma)^2}\frac{I_0}{2V_0}E. \tag{2}$$

The solution of these two equations gives Γ in terms of Γ_0, K, and Q, which must be evaluated separately for the particular circuit being considered.

The field solution is obtained by solving the field equations in various regions and appropriately matching at the boundaries. For a hollow beam of electrons of radius b traveling in the z direction inside a helix of radius a and pitch angle ψ, the matching consists of finding the admittances (H_ϕ/E_z) inside and outside the beam and setting the difference equal to the admittance of the beam. Thus the admittance just outside the beam for an idealized helix will be[1,2]

$$Y_0=\frac{H_{\phi 0}}{E_{z0}}=j\frac{\omega\epsilon}{\gamma}\frac{I_1(\gamma b)-\delta K_1(\gamma b)}{I_0(\gamma b)+\delta K_0(\gamma b)}, \tag{3}$$

where

$$\delta=\frac{1}{K_0^2(\gamma a)}\left(\left(\frac{ka\cot\psi}{\gamma a}\right)^2 I_1(\gamma a)K_1(\gamma a)-I_0(\gamma a)K_0(\gamma a)\right),$$

$$k^2=\omega^2\mu\epsilon,$$

and

$$\gamma^2=-\Gamma^2-k^2.$$

(The I's and K's are modified Bessel functions.) The admittance inside the beam is

$$Y_i=\frac{H_{\phi i}}{E_{zi}}=\frac{j\omega\epsilon}{\gamma}\frac{I_1(\gamma b)}{I_0(\gamma b)}. \tag{4}$$

* Decimal classification: R339.2. Original manuscript received by the Institute, December 19, 1949.
† Bell Telephone Laboratories, Inc., Murray Hill, N. J.

[1] L. J. Chu and J. D. Jackson, "Field theory of traveling-wave tubes," Proc. I.R.E., vol. 36, pp. 853–863; July, 1948.
[2] O. E. H. Rydbeck, "Theory of the traveling-wave tube," *Ericsson Tech.*, no. 46, pp. 3–18, 1948.
[3] J. R. Pierce, "Theory of the beam-type traveling-wave tube," Proc. I.R.E., vol. 35, pp. 111–123; February, 1947.
[4] J. R. Pierce, "Effect of passive modes in traveling-wave tubes," Proc. I.R.E., vol. 36, pp. 993–997; August, 1948.

Boundary conditions require that $E_{z0}=E_{zi}=E_z$ and $H_{z0}-H_{zi}=q/2\pi b$. Combining the boundary conditions, we see that

$$Y_0 - Y_i = \frac{1}{2\pi b}\,\frac{q}{E_z}, \tag{5}$$

where the ratio of q/E_z is given by (2). Thus the field method gives two equations which are equivalent to the circuit and electronic equations of the normal mode method.

Normal Mode Parameters for Thin Beam

The constants appearing in (1) can be evaluated by equating the circuit equation (1) to the circuit equation (5). Thus if $Y_c = Y_o - Y_i$,

$$-\frac{\Gamma^2\Gamma_0 K}{\Gamma^2-\Gamma_0^2} - \frac{2jQK\Gamma^2}{\beta_e} = +\frac{1}{2\pi b Y_c}. \tag{6}$$

The constants can be obtained by expanding each side of (6) in terms of the zero and pole occurring in the vicinity of Γ_0. Thus if γ_0 and γ_p are the zero and pole of Y_c, respectfully,

$$Y_c \approx -(\gamma_p-\gamma_0)\left(\frac{\partial Y_c}{\partial\gamma}\right)_{\gamma=\gamma_0}\left(\frac{\gamma-\gamma_0}{\gamma-\gamma_p}\right), \tag{7}$$

and the two sides of (6) will be equivalent if

$$\Gamma_0^2 = -\gamma_0^2 - k^2, \tag{8}$$

$$\frac{2Q}{\beta_e} = \left(1+\frac{k^2}{\gamma_0^2}\right)^{+1/2}\frac{\gamma_0}{\gamma_p^2-\gamma_0^2}, \tag{9}$$

and

$$\frac{1}{K} = -j\pi b\gamma_0^2\left(1+\frac{k^2}{\gamma_0^2}\right)^{3/2}\left(\frac{\partial Y_c}{\partial\gamma}\right)_{\gamma=\gamma_0}. \tag{10}$$

γ_0 and γ_p can be obtained from (3) and (4) through the implicit equations

$$(ka\cot\psi)^2 = (\gamma_0 a)^2\,\frac{I_0(\gamma_0 a)K_0(\gamma_0 a)}{I_1(\gamma_0 a)K_1(\gamma_0 a)}, \tag{11}$$

$$\frac{I_0(\gamma_p b)}{K_0(\gamma_p b)} = -\frac{1}{K_0^2(\gamma_p a)}\left[\left(\frac{ka\cot\psi}{\gamma_p a}\right)^2 I_1(\gamma_p a)K_1(\gamma_p a) - I_0(\gamma_p a)K_0(\gamma_p a)\right], \tag{12}$$

and $1/K$ is found to be

$$\frac{1}{K} = \pi\sqrt{\frac{\epsilon}{\mu}}\left(1+\frac{k^2}{\gamma_0^2}\right)^{3/2}\frac{ka}{I_0^2(\gamma_0 b)}\,\frac{I_0(\gamma_0 a)}{K_0(\gamma_0 a)}\left[\frac{I_1(\gamma_0 a)}{I_0(\gamma_0 a)} - \frac{I_0(\gamma_0 a)}{I_1(\gamma_0 a)} + \frac{K_0(\gamma_0 a)}{K_1(\gamma_0 a)} - \frac{K_1(\gamma_0 a)}{K_0(\gamma_0 a)} + \frac{4}{\gamma_0 a}\right]. \tag{13}$$

The equations for γ_0 and K are the same as those given by Pierce,[3,4] evaluated by solving the field equations for the helix without electrons present. The evaluation of γ_p, and thus Q, represents a new contribution. Values of

$$Q\,\frac{\gamma_0}{\beta_e}\left(1+\frac{k^2}{\gamma_0^2}\right)^{-1/2}$$

are plotted in Fig. 1 as a function of $\gamma_0 a$ for various ratios of b/a. (It should be noted that for most practical applications the factor

$$\frac{\gamma_0}{\beta_e}\left(1+\frac{k^2}{\gamma_0^2}\right)^{-1/2}$$

is very close to unity, so that the ordinate is practically the value of Q itself.)

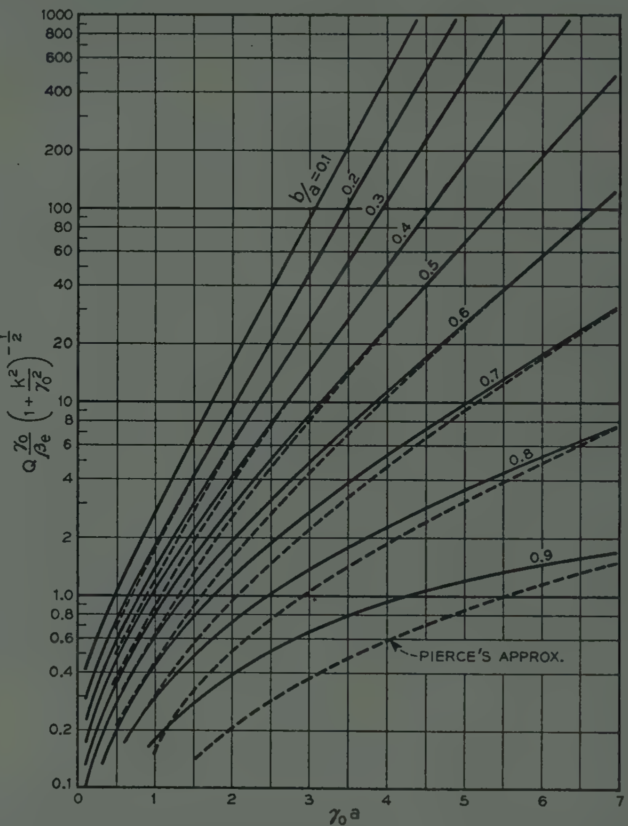

Fig. 1—Passive mode parameter Q for a hollow beam of electrons of radius b inside a helix of radius a and natural propagation constant γ_0. The solid line was obtained by equating the circuit equation of the normal mode method, which defines Q, with a corresponding circuit equation found from the field theory method. The dashed line was obtained by Pierce[5] from a solution of the field equations for a conductor replacing the helix.

Pierce has given a method for estimating Q[5] based on the solution of the field equations for a conductor replacing the helix and considering the resultant field to be

$$-\frac{2jKQ\Gamma^2}{\beta_e}\,q.$$

His estimate of Q is plotted as the dashed lines of Fig. 1.

[5] J. R. Pierce, "Traveling-wave tubes," (in process of publication).

Thick Beam Case

For an electron beam which entirely fills the space out to the radius b, the electronic equations of both the normal mode method and the field method are altered in such a way as to complicate the solution considerably. In order to find a solution for this case, some simplifying assumptions must be made. A convenient type of assumption is to replace the thick beam by an "equivalent" thin beam, for which the solutions have already been worked out.

Two beams will be equivalent if the value of H_ϕ/E_z is the same outside the beams, since the matching to the circuit depends only on this admittance. The problem then of making a thin beam equivalent of a thick beam is the problem of arranging the position and current of a thin beam to give the same admittance at the radius b of the thick beam. This is, of course, impossible for all values of γ. It is desirable, therefore, that the admittances be the same close to the complex values of γ which will eventually solve the equations.

The solution of the field equations for the solid beam yields the value for H_ϕ/E_z[1,2] at the radius b as

$$\frac{H_\phi}{E_z} = \frac{j\omega\epsilon}{\gamma}\,\frac{nI_1(n\gamma b)}{I_0(n\gamma b)}, \tag{14}$$

where

$$n^2 = 1 + \frac{1}{k}\sqrt{\frac{\mu}{\epsilon}}\,\frac{\beta_e I_0}{2\pi b^2 V_0}\,\frac{1}{(j\beta_e - \Gamma)^2}. \tag{15}$$

Thus the electronic equation for the solid beam which must be solved simultaneously with the circuit equation (given above by either the normal mode approximation or the field solution) must be

$$Y_e = \frac{H_\phi}{E_z} - Y_i = \frac{j\omega\epsilon b}{\gamma b}\left[\frac{nI_1(n\gamma b)}{I_0(n\gamma b)} - \frac{I_1(\gamma b)}{I_0(\gamma b)}\right]. \tag{16}$$

Complex roots for γ will be expected in the vicinity of real values of γ for which $Y_e \approx Y_c$ and

$$\frac{dY_e}{d\gamma} \approx \frac{dY_c}{d\gamma}.$$

By plotting Y_e and Y_c versus real values of γ, it is found that the two curves become tangent close to the value of γ for which $n=0$, using typical operating conditions (Fig. 2). Our procedure for choosing a hollow beam equivalent of the solid beam then will be to equate the values of Y_e and $dY_e/d\gamma$ at $n=0$. This will give us two equations from which to solve for the electron beam diameter and dc current for the equivalent hollow beam.

If the hollow beam is placed at the radius sb with a current of tI_0, the value of H_ϕ/E_z at the radius b gives the value for Y_{eH} as

$$Y_{eH} = \left(\frac{H_\phi}{E_z}\right)_b - Y_i = -j\omega\epsilon b\,\frac{t}{2}\,(1-n^2)\,\frac{I_0^2(s\gamma b)}{I_0^2(\gamma b)}$$

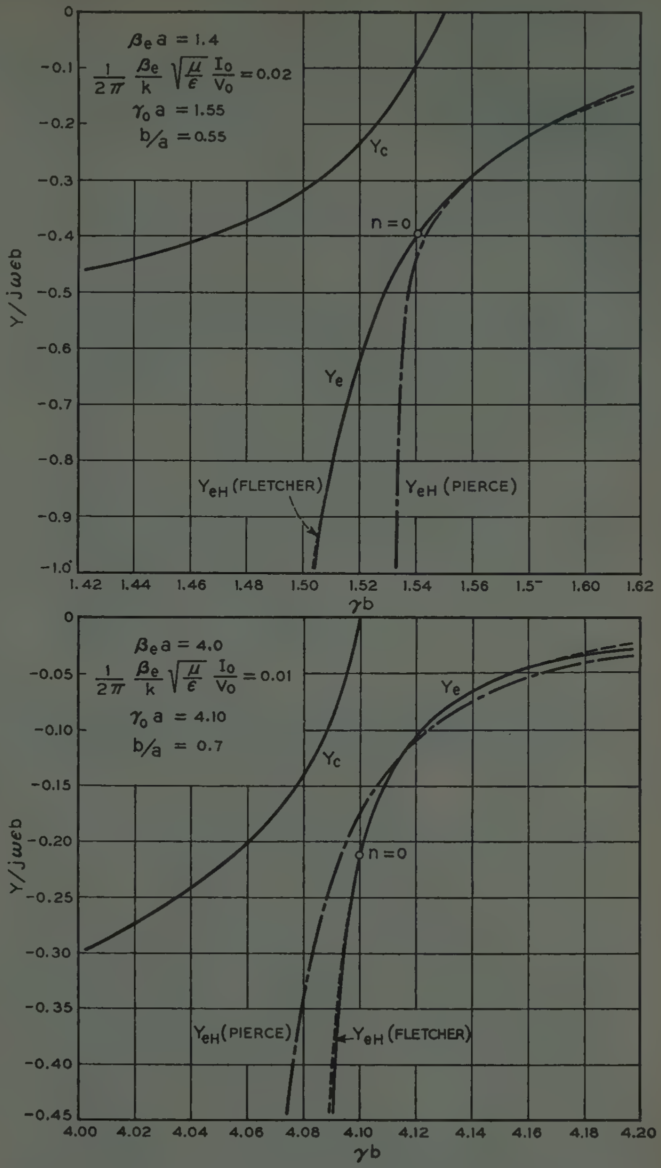

Fig. 2—Electronic admittance Y_e of a solid electron beam of radius b and circuit admittance Y_c of a helix of radius a plotted versus real values of the propagation constant γ in the vicinity of where $dY_e/d\gamma = dY_c/d\gamma$ where complex solutions for γ are expected, for two typical sets of operating conditions. Plotted on the same graph is the electron admittance Y_{eH} for two equivalent hollow electron beams: the dashed curve (Fletcher) is matched to Y_e at $n=0$, while the dot-dashed curve (Pierce) is matched at $n=1$ (off the graph).

$$\cdot\left(1 - \gamma^2 b^2 I_0^2(s\gamma b)\,\frac{t}{2}\,(1-n^2)\right.$$
$$\left.\cdot\left[\frac{K_0(s\gamma b)}{I_0(s\gamma b)} - \frac{K_0(\gamma b)}{I_0(\gamma b)}\right]\right)^{-1}. \tag{17}$$

Equating this with (16) at $n=0$ yields the equation

$$\frac{1}{t} = \frac{1}{2}\,\theta^2 I_0^2(s\theta)\left[\frac{K_0(s\theta)}{I_0(s\theta)} + \frac{K_1(\theta)}{I_1(\theta)}\right], \tag{18}$$

where $\theta = \gamma_0 b$ and γ_0 is the value of γ at $n=0$; i.e., for $\gamma_0 \gg k$

$$\gamma_e = \beta_e + \sqrt{\frac{1}{k}\sqrt{\frac{\mu}{\epsilon}}\frac{\beta_e I_0}{2\pi b^2 V_0}} \approx \beta_e. \tag{19}$$

In the vicinity of $n=0$, n varies very rapidly with γ, and hence matching $(\partial Y_e/\partial n)\gamma$ is practically the same as matching $dY_e/d\gamma$. With this approximation (16) and (17) can be differentiated with respect to n and set equal at $n=0$ to yield the second relation

$$\frac{1}{t} = \theta^2 I_0^2(\theta) I_0^2(s\theta)\left[\frac{K_0(s\theta)}{I_0(s\theta)} + \frac{K_1(\theta)}{I_1(\theta)}\right]^2. \tag{20}$$

Equations (18) and (20) can then be solved to give the implicit equation for s as

$$\frac{K_0(s\theta)}{I_0(s\theta)} = -\frac{K_1(\theta)}{I_1(\theta)} + \frac{1}{2I_1^2(\theta)}, \tag{21}$$

and the simpler equation for t

$$t = \frac{4}{\theta^2}\frac{I_1^2(\theta)}{I_0^2(s\theta)}. \tag{22}$$

s and t are plotted as a function of θ in Fig. 3. The value of Y_{eH} using these values of s and t is compared in Fig. 2 with Y_e in the vicinity of where Y_e is almost tangent to Y_e for two typical sets of operating conditions.

It is of course possible to pick other criteria for determining an "equivalent" hollow beam. Pierce has suggested[5] expanding the Y_e and Y_{eH} in terms of $(1-n^2)$ and equating the coefficients of the first two terms. The

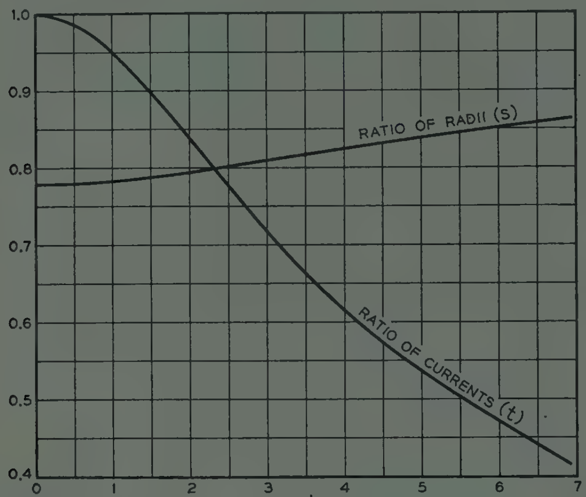

Fig. 3—Parameters of the hollow electron beam which is matched to the solid electron beam of radius b and current I_0 at $\gamma=\gamma_e\approx\beta_e$, where $n=0$. sb is the radius and tI_0 is the current of the equivalent hollow beam.

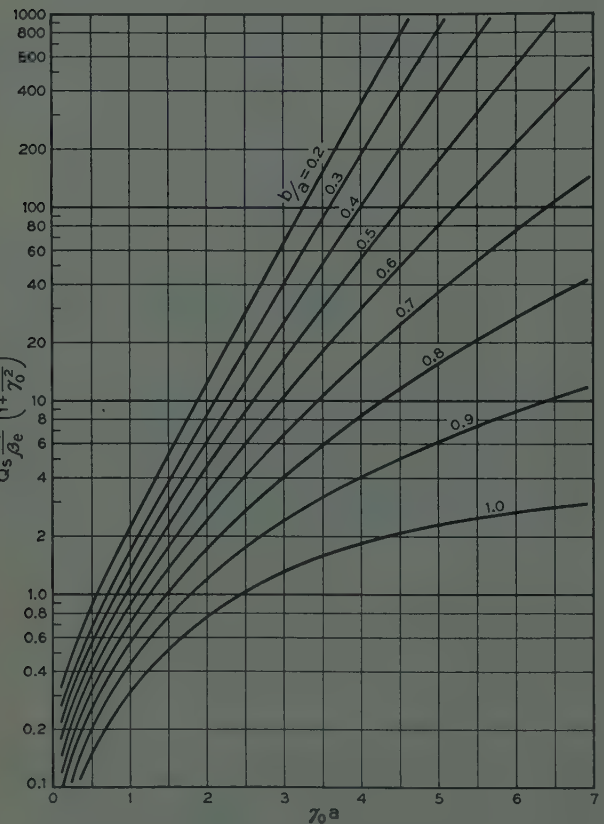

Fig. 4—Passive mode parameter Q_s for a solid beam of electrons of radius b inside a helix of radius a and natural propagation constant γ_0, obtained from the equivalent hollow beam parameters of Fig. 3 taken at $\gamma_e=\gamma_0$. All the normal mode solutions which have been found[3-5] for a hollow beam will be approximately valid for a solid beam if Q is replaced by Q_s and K is replaced by K_s (Fig. 5).

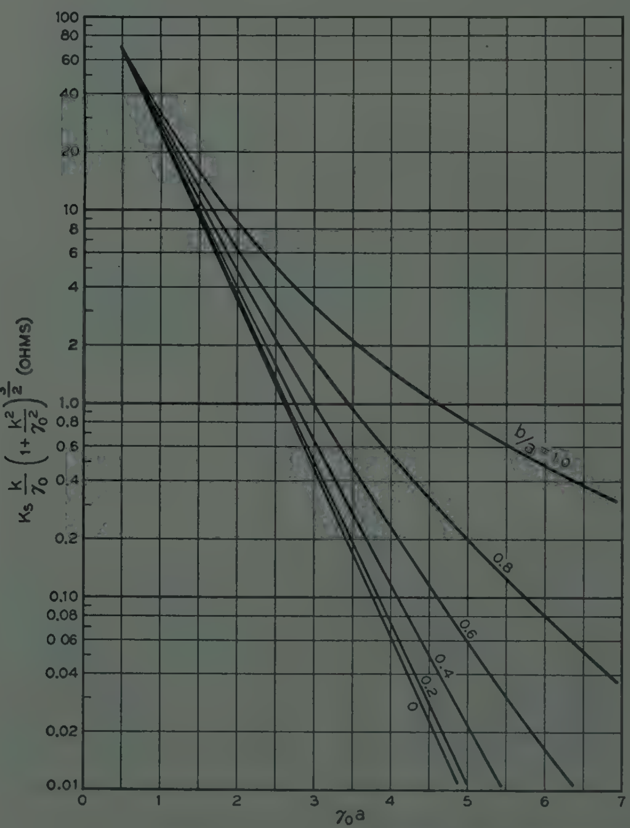

Fig. 5—Circuit impedance K_s for a solid beam of electrons of radius b inside a helix of radius a and natural propagation constant γ_0, obtained from the equivalent hollow beam parameters of Fig. 3 taken at $\gamma_e=\gamma_0$. K_s should replace $K=(E^2/2\beta^2P)^{3-5}$ in order for the normal mode solutions for a hollow beam to be applicable to a solid beam.

values of s and t found by this method determine values of Y_{eH} shown in Fig. 2. The greater departure from the true curve of Y_e would indicate that this approximation is not as good as that described above.

It is now possible to find the values of Q_s and K_s appropriate to the solid beam. Thus if $Q(\gamma_0 a, b/a)$ and $K(\gamma_0 a, b/a)$ are the values for the hollow beam calculated from (9), (12), and (13),

$$Q_s = Q\left(\gamma_0 a, s\frac{b}{a}\right), \tag{23}$$

and

$$K_s = tK\left(\gamma_0 a, s\frac{b}{a}\right). \tag{24}$$

The t is placed in front of K in (24) because tI_0 and K appear in the thin beam solutions only in the combination tI_0K. Using tK instead of K allows us to use I_0, the actual value of the current in the solid beam in the solutions instead of tI_0, the equivalent current. Values of

$$Q_s\frac{\gamma_0}{\beta_e}\left(1+\frac{k^2}{\gamma_0^2}\right)^{-1/2} \quad \text{and}$$

$$K_s\frac{k}{\gamma_0}\cdot\left(1+\frac{k^2}{\gamma_0^2}\right)^{+3/2} \quad \text{are plotted versus}$$

$\gamma_0 a$ in Figs. 4 and 5 for different values of b/a and for values of t and s taken at $\gamma_e=\gamma_0$. All the solutions obtained by Pierce[3–5] for the hollow beam will be valid for the solid beam if Q_s and K_s are substituted for Q and K.

ACKNOWLEDGMENT

The writer wishes to acknowledge his indebtedness to J. R. Pierce, who suggested the general approach used in this paper.

A Simplified Derivation of Linear Least Square Smoothing and Prediction Theory*

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Summary—**The central results of the Wiener-Kolmogoroff smoothing and prediction theory for stationary time series are developed by a new method. The approach is motivated by physical considerations based on electric circuit theory and does not involve integral equations or the autocorrelation function. The cases treated are the "infinite lag" smoothing problem, the case of pure prediction (without noise), and the general smoothing prediction problem. Finally, the basic assumptions of the theory are discussed in order to clarify the question of when the theory will be appropriate, and to avoid possible misapplication.**

I. INTRODUCTION

IN A CLASSIC REPORT written for the National Defense Research Council,[1] Wiener has developed a mathematical theory of smoothing and prediction of considerable importance in communication theory. A similar theory was independently developed by Kolmogoroff[2] at about the same time. Unfortunately the work of Kolmogoroff and Wiener involves some rather formidable mathematics—Wiener's yellow-bound report soon came to be known among bewildered engineers as "The Yellow Peril"—and this has prevented the wide circulation and use that the theory deserves. In this paper the chief results of smoothing theory will be developed by a new method which, while not as rigorous or general as the methods of Wiener and Kolmogoroff, has the advantage of greater simplicity, particularly for readers with a background of electric circuit theory. The mathematical steps in the present derivation have, for the most part, a direct physical interpretation, which enables one to see intuitively what the mathematics is doing.

II. THE PROBLEM AND BASIC ASSUMPTIONS

The main problem to be considered may be formulated as follows. We are given a perturbed signal $f(t)$ which is the sum of a true signal $s(t)$, and a perturbing noise $n(t)$

$$f(t) = s(t) + n(t).$$

It is desired to operate on $f(t)$ in such a way as to obtain, as well as possible, the true signal $s(t)$. More generally, one may wish to combine this smoothing operation with prediction, i.e., to operate on $f(t)$ in such a way as to obtain a good approximation to what $s(t)$ will be in the future, say α seconds from now, or to what it was in the past, α seconds ago. In these cases we wish to approximate $s(t+\alpha)$ with α positive or negative, respectively. The situation is indicated schematically in Fig. 1; the problem is that of filling the box marked "?."

* Decimal classification: 510. Original manuscript received by the Institute, July 13, 1949; revised manuscript received, January 17, 1950.

† Bell Telephone Laboratories, Inc., Murray Hill, N. J.

[1] N. Wiener, "The Interpolation, Extrapolation, and Smoothing of Stationary Time Series," National Defense Research Committee; reprinted as a book, together with two expository papers by N. Levinson, published by John Wiley and Sons, Inc., New York, N. Y., 1949.

[2] A. Kolmogoroff, "Interpolation und Extrapolation von Stationären Zufälligen Folgen," *Bull. Acad. Sci.* (URSS) Sér. Math. 5, pp. 3–14; 1941.

It will be seen that this problem and its generalizations are of wide application, not only in communication theory, but also in such diverse fields as economic prediction, weather forecasting, gunnery, statistics, and the like.

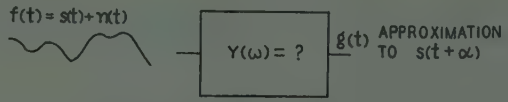

Fig. 1—The smoothing and prediction problem.

The Wiener-Kolmogoroff theory rests on three main assumptions which determine the range of application of the results. These assumptions are:

1. The time series represented by the signal $s(t)$ and the noise $n(t)$ are *stationary*. This means essentially that the statistical properties of the signal and of the noise do not change with time. The theory cannot properly be applied, for example, to *long-term* economic effects, since the statistics of, say, the stock market were not the same in 1850 as they are today.

2. The criterion of error of approximation is taken to be the *mean-square discrepancy* between the actual output and the desired output. In Fig. 1 this means that we fill the box "?" in such a way as to minimize the mean-square error $\overline{[g(t)-s(t+\alpha)]^2}$, the average being taken over all possible signal and noise functions with each weighted according to its probability of occurrence. This is called the *ensemble* average.

3. The operation to be used for prediction and smoothing is assumed to be a *linear* operation on the available information, or, in communication terms, the box is to be filled with a linear, physically realizable, filter. The available information consists of the past history of the perturbed signal, i.e., the function $f(t)$ with $t \leqq t_1$, where t_1 is the present time. A linear, physically realizable filter performs a linear operation on $f(t)$ over just this range, as we will see later in connection with equations (3) and (4).

The theory may therefore be described as *linear least square prediction and smoothing of stationary time series*. It should be clearly realized that the theory applies only when these three assumptions are satisfied, or at least are approximately satisfied. If any one of the conditions is changed or eliminated, the prediction and smoothing problem becomes very difficult mathematically, and little is known about usable explicit solutions. Some of the limitations imposed by these assumptions will be discussed later.

How is it possible to predict at all the future behavior of a function when all that is known is a perturbed version of its past history? This question is closely associated with the problems of causality and induction in philosophy and with the significance of physical laws. In general, physical prediction depends basically on an *assumption* that regularities which have been observed in the past will obtain in the future. This assumption can never be proved deductively, i.e., by purely mathematical argument, since we can easily conceive mathematical universes in which the assumption fails. Neither can it be established inductively, i.e., by a generalization from experiments, for this very generalization would assume the proposition we were attempting to establish. The assumption can be regarded only as a central postulate of physics.

Classical physics attempted to reduce the physical world to a set of strict causal laws. The future behavior of a physical system is then exactly predictable from a knowledge of its past history, and in fact all that is required is a knowledge of the present state of the system. Modern quantum physics has forced us to abandon this view as untenable. The laws of physics are now believed to be only statistical laws, and the only predictions are statistical predictions. The "exact" laws of classical physics are subject to uncertainties which are small when the objects involved are large, but are relatively large for objects on the atomic scale.

Linear least square smoothing and prediction theory is based on statistical prediction. The basic assumption that statistical regularities of the past will hold in the future appears in the mathematics as the assumption that the signal and noise are *stationary* time series. This implies, for example, that a statistical parameter of the signal averaged over the past will give the same value as this parameter averaged over the future.

The prediction depends essentially on the existence of correlations between the future value of the signal $s(t_1+\alpha)$ where t_1 is the present time, and the known data $f(t)=s(t)+n(t)$ for $t \leqq t_1$. The assumption that the prediction is to be done by a *linear* operation implies that the only type of correlation that can be used is *linear* correlation, i.e., $\overline{s(t_1+\alpha)\, f(t)}$. If this correlation were zero for all $t \leqq t_1$, no significant linear prediction would be possible, as will appear later. The best mean-square estimate of $s(t_1+\alpha)$ would then be zero.

III. Properties of Linear Filters

In this section, a number of well-known results concerning filters will be summarized for easy reference. A linear filter can be characterized in two different but equivalent ways. The first and most common description is in terms of the complex transfer function $Y(\omega)$. If a pure sine wave of angular frequency ω_1 and amplitude E is used as input to the filter, the output is also a pure sine wave of frequency ω_1 and amplitude $|Y(\omega_1)|E$. The phase of the output is advanced by the angle of $Y(\omega_1)$, the phase of the filter at this frequency. It is frequently convenient to write the complex transfer function $Y(\omega)$ in the form $Y(\omega)=e^{A(\omega)}\, e^{iB(\omega)}$ where $A(\omega)=\log |Y(\omega)|$ is the gain, and $B(\omega)=\text{angle}\,[Y(\omega)]$ is the phase. Since we will assume that the filter can contain an ideal amplifier as well as passive elements, we can add any constant to A to make the absolute level of the gain as high as we please.

The second characterization of a filter is in terms of time functions. Let $K(t)$ be the inverse Fourier transform of $Y(\omega)$

$$K(t) = \frac{1}{2\pi}\int_{-\infty}^{\infty} Y(\omega)e^{i\omega t}d\omega. \tag{1}$$

Then $Y(\omega)$ is the direct Fourier transform of $K(t)$

$$Y(\omega) = \int_{-\infty}^{\infty} K(t)e^{-i\omega t}dt. \tag{2}$$

Knowledge of $K(t)$ is completely equivalent to knowledge of $Y(\omega)$; either of these may be calculated if the other is known.

The time function $K(t)$ is equal to the output obtained from the filter in response to a unit impulse impressed upon its input at time $t=0$, as illustrated by Fig. 2. From this relation we can readily obtain the response

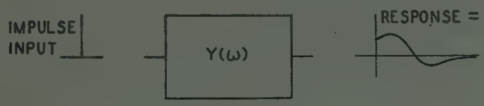

Fig. 2—Impulsive response of a network.

of the filter to any artibrary input $f(t)$. It is merely necessary to divide the input wave into a large number of thin vertical slices, as shown by Fig. 3. Each slice can be regarded as an impulse of strength $f(t)dt$, which will pro-

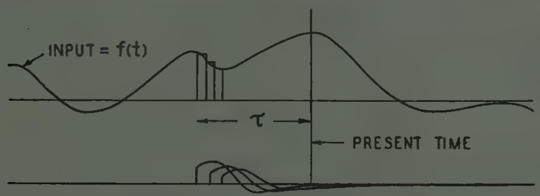

Fig. 3—Response to an arbitrary input as a sum of impulsive responses.

duce a response $f(t)dt\,K(t_1-t)$ at any subsequent time t_1. Upon adding together the contributions of all the slices we have the well-known formula

$$g(t_1) = \int_{-\infty}^{t_1} f(t)K(t_1 - t)dt \tag{3}$$

for the total response at t_1.

For the study of smoothing theory, (3) can conveniently be replaced by a slightly different expression. Setting $\tau=t_1-t$, we have

$$g(t_1) = \int_0^{\infty} f(t_1 - \tau)K(\tau)d\tau. \tag{4}$$

In this formulation, τ stands for the age of the data, so that $f(t_1-\tau)$ represents the value of the input wave τ seconds ago. $K(\tau)$ is a function like the impulsive admittance, but projecting into the past rather than the future, as shown by Fig. 4. It is evidently a weighting function by which the voltage inputs in the past must be multiplied to determine their contributions to the present output.

Criteria for physical realizability can be given in terms of either the K function or Y. In terms of the impulsive response $K(t)$, it is necessary that $K(t)$ be zero for $t<0$; that is, the network cannot respond to an impulse before the impulse arrives. Furthermore, $K(t)$ must approach zero (with reasonable rapidity) as $t\rightarrow+\infty$. Thus the effect of an impulse at the present time should eventually die out.

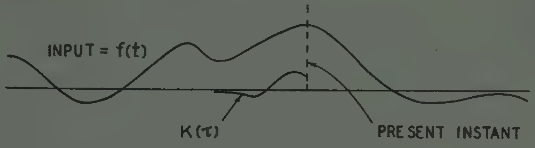

Fig. 4—Response as a weighted average of the past input.

These requirements are also meaningful in terms of the interpretation of K as a weighting function. Thus, the filter cannot apply a weighting to parts of the input that have yet to occur; hence, $K(\tau)=0$ for $\tau<0$. Also the effect of the very remote past should gradually die out, so that $K(\tau)$ should approach zero as $\tau\rightarrow\infty$. It may also be noted that these conditions are also sufficient for physical realizability in the sense that any impulsive response $K(t)$ satisfying them can be approximated as closely as desired with a passive lumped element network, together with a single amplifier.

In terms of frequency response, the principal condition for physical realizability is that $Y(\omega)$, considered as a function of the complex variable ω, must be an analytic function in the half plane defined by $Im(\omega)<0$. In addition, the function must behave on the real frequency axis[3] in such a way that

$$\int_0^{\infty} \frac{\log |Y(\omega)|}{1+\omega^2}d\omega \tag{5}$$

is a finite number.

The requirements of physical realizability lead to the well-known loss-phase relations. For a given gain $A=\log|Y(\omega)|$ satisfying (5), there is a minimum possible phase characteristic. This phase is given by

$$B(\omega_0) = \frac{2\omega_0}{\pi}\int_0^{\infty} \frac{A(\omega) - A(\omega_0)}{\omega^2 - \omega_0^2}d\omega. \tag{6}$$

If the square of the prescribed gain $|Y(\omega)|^2 = Y(\omega)\overline{Y}(\omega)$ is a rational function of ω, say, $P_1(\omega)/P_2(\omega)$ where $P_1(\omega)$ and $P_2(\omega)$ are polynomials, the minimum phase characteristic can be found as follows: Calculate the roots of $P_1(\omega)$ and $P_2(\omega)$ and write $|Y(\omega)|^2$ as

$$|Y(\omega)|^2 = k^2\frac{(\omega-\alpha_1)(\omega-\bar{\alpha}_1)(\omega-\alpha_2)(\omega-\bar{\alpha}_2)\cdots}{(\omega-\beta_1)(\omega-\bar{\beta}_1)(\omega-\beta_2)(\omega-\bar{\beta}_2)\cdots} \tag{7}$$

[3] Including the point at infinity. Actual physical networks will, of course, always have zero gain at infinite frequency, and the above requirement shows that the approach to zero cannot be too rapid. An approach of the type ω^{-n} ($6n$ db per octave) is possible but $e^{-|\omega|}$ or $e^{-\omega^2}$ causes the integral in (5) to diverge and is physically unrealizable.

where $\alpha_1, \alpha_2 \cdots \beta_1, \beta_2 \cdots$ all have imaginary parts >0. That is, these are the roots and poles of $|Y(\omega)|^2$ in the upper-half plane and the conjugate terms are the corresponding roots and poles in the lower-half plane. The minimum phase network then has the transfer function

$$Y(\omega) = k \frac{(\omega - \alpha_1)(\omega - \alpha_2) \cdots}{(\omega - \beta_1)(\omega - \beta_2) \cdots}. \tag{8}$$

A minimum phase network has the important property that its inverse, with the transfer function $Y^{-1}(\omega)$, is also physically realizable.[4] If we pass a signal $f(t)$ through the filter $Y(\omega)$, we can recover it in its original form by passing it through the inverse filter. Moreover, the recovery takes place *without loss of time*. On the other hand, there is no physically realizable exact inverse for a nonminimum phase network. The best we can do is to provide a structure which has all the properties of the theoretical inverse, except for an extra phase lag. The extra phase lag can be equalized to give a constant delay by the addition of a suitable phase equalizer, but it cannot be eliminated. Thus, if we transmit a signal through a nonminimum network, we can recover it only after a delay; that is, we obtain $f(t-\alpha)$ for some positive α.

IV. General Expression for the Mean-Square Error

Suppose we use for the predicting-smoothing filter in Fig. 1 a filter with transfer characteristic $Y(\omega)$. What is the mean-square error in the prediction? Since different frequencies are incoherent, we can calculate the average power in the error function

$$e(t) = s(t + \alpha) - g(t) \tag{9}$$

by adding the contributions due to different frequencies. Consider the components of the signal and noise of a particular frequency ω_1. It will be assumed that the signal and noise are incoherent at all frequencies. Then, at frequency ω_1 there will be a contribution to the error due to noise equal to $N(\omega_1)|Y(\omega_1)|^2$, where $N(\omega_1)$ is the average noise power at that frequency ω_1.

There is also a contribution to the error due to the failure of components of the signal, after passing through the filter, to be correct. A component of frequency ω_1 should be advanced in phase by $\alpha\omega_1$, and the amplitude of the output should be that of the input. Hence there will be a power error

$$|Y(\omega_1) - e^{i\alpha\omega_1}|^2 P(\omega_1) \tag{10}$$

where $P(\omega_1)$ is the power in the signal at frequency ω_1.

The total mean-square error due to components of frequency ω_1 is the sum of these two errors, or

$$E_{\omega_1} = |Y(\omega_1)|^2 N(\omega_1) + |Y(\omega_1) - e^{i\alpha\omega_1}|^2 P(\omega_1), \tag{11}$$

[4] If the original function has a zero at infinity, so that the required inverse has a pole there, there are complications, but an adequate approximation can be obtained in physical cases.

and the total mean-square error for all frequencies is

$$E = \int_{-\infty}^{\infty} [|Y(\omega)|^2 N(\omega) + |Y(\omega) - e^{i\alpha\omega}|^2 P(\omega)] d\omega. \tag{12}$$

The problem is to minimize E by proper choice of $Y(\omega)$, remembering that $Y(\omega)$ must be physically realizable.

Several important conclusions can be drawn merely from an inspection of (12). The only way in which the signal and noise enter this equation is through their power spectra. Hence, the only statistics of the signal and noise that are needed to solve the problem are these spectra. Two different types of signal with the same spectrum will lead to the same optimal prediction filter and to the same mean-square error. For example, if the signal is speech it will be predicted by the same filter as would be used for prediction of a thermal noise which has been passed through a filter to give it the same power spectrum as speech.

Speaking somewhat loosely, this means that a linear filter can make use only of statistical data pertaining to the *amplitudes* of the different frequency components; the statistics of the relative phase angles of these components cannot be used. Only by going to nonlinear prediction can such statistical effects be used to improve the prediction.

It is also clear that in the linear least square problem we can, if we choose, replace the signal and noise by any desired time series which have the same power spectra. This will not change the optimal filter or the mean square error in any way.

V. The Pure Smoothing Problem

The chief difficulty in minimizing (12) for the mean-square error lies in properly introducing the condition that $Y(\omega)$ must be a physically realizable transfer function. We will first solve the problem with this constraint waived and then from this solution construct the best physically realizable filter.

Waiving the condition of physical realizability is equivalent to admitting any $Y(\omega)$, or, equivalently, any impulsive response $K(t)$. Thus, $K(t)$ is not necessarily zero for $t<0$, and we are allowing a weighting function to be applied to both the past and future of $f(t)$. In other words, we assume that the entire function $f(t) = s(t)+n(t)$ from $t=-\infty$ to $t=+\infty$ is available for use in prediction.

In (12), suppose

$$Y(\omega) = C(\omega)e^{iB(\omega)} \tag{13}$$

with $C(\omega)$ and $B(\omega)$ real. Then (12) becomes

$$E = \int_{-\infty}^{\infty} [C^2 N + P(C^2 + 1 - 2C \cos(\alpha\omega - B))] d\omega \tag{14}$$

where $C(\omega)$, $N(\omega)$, and the like are written as C, N, and so forth, for short. Clearly, the best choice of $B(\omega)$ is $B(\omega) = \alpha\omega$ since this maximizes $\cos(\alpha\omega - B(\omega))$. Then (14) becomes

$$E = \int_{-\infty}^{\infty} [C^2(P+N) - 2PC + P] d\omega. \quad (15)$$

Completing the square in C by adding and subtracting $P^2/(P+N)$ we obtain

$$E = \int_{-\infty}^{\infty} \left[C^2(P+N) - 2PC + \frac{P^2}{P+N} - \frac{P^2}{P+N} + P \right] d\omega \quad (16)$$

or

$$E = \int_{-\infty}^{\infty} \left(\left[\sqrt{P+N}\, C - \frac{P}{\sqrt{P+N}} \right]^2 + \frac{PN}{P+N} \right) d\omega. \quad (17)$$

The bracketed term is the square of a real number, and therefore positive or zero. Clearly, to minimize E we choose C to make this term everywhere zero, thus

$$C(\omega) = \frac{P(\omega)}{P(\omega) + N(\omega)}$$

and

$$Y(\omega) = \frac{P(\omega)}{P(\omega) + N(\omega)} e^{i\alpha\omega}. \quad (18)$$

With this choice of $Y(\omega)$ the mean square error will be, from (17),

$$E = \int_{-\infty}^{\infty} \frac{P(\omega)N(\omega)}{P(\omega) + N(\omega)} d\omega. \quad (19)$$

The best weighting function is given by the inverse Fourier transform of (18)

$$K(t) = \frac{1}{2\pi} \int_{-\infty}^{\infty} \frac{P(\omega)}{P(\omega) + N(\omega)} e^{i\omega(t+\alpha)} d\omega. \quad (20)$$

This $K(t)$ will, in general, extend from $t = -\infty$ to $t = +\infty$. It does not represent the impulsive response of a physical filter. However, it is a perfectly good weighting function. If we could wait until all the function $s(t)+n(t)$ is available, it would be the proper one to apply in estimating $s(t+\alpha)$.

To put the question in another way, the weighting $K(\tau)$ can be obtained in a physical filter if sufficient delay is allowed so that $K(\tau)$ is substantially zero for the future. Thus we have solved here the "infinite lag" smoothing problem. Although $Y(\omega)$ in (18) is nonphysical, $Y(\omega)e^{-i\beta\omega}$ will be physical, or nearly so, if β is taken sufficiently large.

VI. The Pure Prediction Problem

We will now consider another special case, that in which there is no perturbing noise. The problem is then one of pure prediction. What is the best estimate of $s(t+\alpha)$ when we know $s(t)$ from $t = -\infty$ up to $t = 0$?

We have seen that the solution will depend only on the power spectra of the signal and noise, and since we are now assuming the noise to be identically zero, the solution depends only on the power spectrum $P(\omega)$ of the signal. This being the case, we may replace the actual signal by any other having the same spectrum. The solution of the best predicting filter will be the same for the altered problem as for the original problem.

Any desired spectrum $P(\omega)$ can be obtained by passing wide-band resistance noise or "white" noise through a shaping filter whose gain characteristic is $\sqrt{P(\omega)}$. The spectrum of resistance noise is flat (at least out to frequencies higher than any of importance in communication work), and the filter merely multiplies this constant spectrum by the square of the filter gain $P(\omega)$. The phase characteristic of the filter can be chosen in any way consistent with the conditions of physical realizability. Let us choose the phase characteristic so that the filter is minimum phase for the gain $\sqrt{P(\omega)}$. Then the filter has a phase characteristic given by

$$B(\omega_0) = \frac{-\omega_0}{\pi} \int_0^{\infty} \frac{\log P(\omega) - \log P(\omega_0)}{\omega^2 - \omega_0^2} d\omega. \quad (21)$$

Furthermore, this minimum phase network has a physically realizable inverse.

We have now reduced the problem to the form shown in Fig. 5. What is actually available is the function $s(t)$ up to $t=0$. However, this is equivalent to a knowledge of

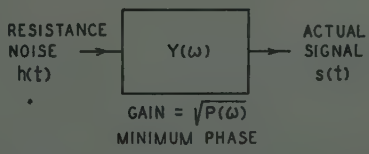

Fig. 5—Construction of actual signal spectrum from resistance noise.

the resistance noise $h(t)$ up to $t=0$, since the filter Y has a physically realizable inverse and we can pass the available function $s(t)$ through the inverse Y^{-1} to obtain $h(t)$.

The problem, therefore, is equivalent to asking what is the best operation to apply to $h(t)$ in order to approximate $s(t+\alpha)$ in the least square sense? The question is easily answered. A resistance noise can be thought of as made up of a large number of closely spaced and very short impulses, as indicated in Fig. 6. The impulses have a Gaussian distribution of amplitudes and are statistically independent of each other. Each of these impulses entering the filter Y produces an output corresponding to the impulsive response of the filter, as shown at the right of Fig. 6, and the signal $s(t)$ is the sum of these elementary responses.

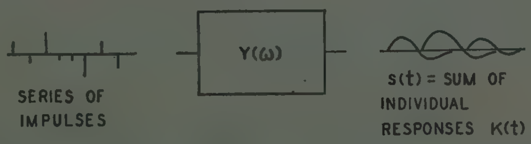

Fig. 6—Result of resistance noise input.

What is known is $h(t)$ up to the present; that is, we know effectively the impulses up to $t=0$ and nothing about those after $t=0$; these have not yet occurred. The future signal $s(t+\alpha)$ is thus made up of two parts; the

tails of responses due to impulses that have already occurred, and a part due to impulses which will occur between the present time and time $t=\alpha$. The first part is completely predictable, while the second part is entirely unpredictable, being statistically independent of our available information at the present time.

The total result of the first part can be obtained by constructing a filter whose impulsive response is the tail of the impulsive response of filter Y moved ahead α seconds. This is shown in Fig. 7 where $K_1(t)$ is the new impulsive response and $K(t)$ the old one. The new filter responds to an impulse entering *now* as the filter Y will respond in α seconds. It responds to an impulse that entered one second ago as Y will respond in α seconds to one that entered it one second ago. In short, if $h(t)$ is used as input to this new filter Y_1, the output now will be the predictable part of the future response of Y to the same input α seconds from now.

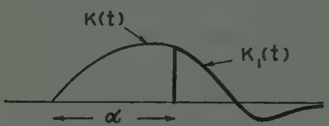

Fig. 7—Construction of the physical response $K_1(t)$ from $K(t)$.

The second, or unpredictable part of the future response, corresponding to impulses yet to occur, cannot, of course, be constructed. We know, however, that the mean value of this part must be zero, since future impulses are as likely to be of one sign as the other. Thus the arithmetic average, or center of gravity, of the possible future responses is the predictable part given by the output of Y_1. But it is well known that the arithmetic mean of any distribution is the point about which the mean-square error is the least. The output of Y_1 is thus the desired prediction of $s(t+\alpha)$.

In constructing Y_1 we assumed that we had available the white noise $h(t)$. Actually, however, our given data is the signal $s(t)$. Consequently, the best operation on the given data is $Y_1(\omega)\ Y^{-1}(\omega)$, the factor $Y^{-1}(\omega)$ reducing the function $s(t)$ to the white noise $h(t)$, and the second operation $Y_1(\omega)$ performing the best prediction based on $h(t)$.

The solution may be summarized as follows:

1. Determine the minimum phase network having the gain characteristic $\sqrt{P(\omega)}$. Let the complex transfer characteristic of this filter be $Y(\omega)$, and its impulsive response $K(t)$.

2. Construct a filter whose impulsive response is

$$\begin{aligned} K_1(t) &= K(t+\alpha) \quad \text{for} \quad t \geq 0 \\ &= 0 \qquad\qquad\ \ \text{for} \quad < 0. \end{aligned} \tag{22}$$

Let the transfer characteristic of this network be $Y_1(\omega)$.

3. The optimal least square predicting filter then has a characteristic

$$Y_1(\omega)Y^{-1}(\omega). \tag{23}$$

The mean-square error E in the prediction is easily calculated. The error is due to impulses occurring from time $t=0$ to $t=\alpha$. Since these impulses are uncorrelated, the mean-square sum of the errors is the sum of the individual mean-square errors. The individual pulses are effective in causing mean-square error in proportion to the square of $K(\alpha-t)$. Hence, the total mean-square error will be given by

$$\begin{aligned} E^2 &= \rho \int_0^\alpha K^2(\alpha - t)dt \\ &= \rho \int_0^\alpha K^2(t)dt \end{aligned} \tag{24}$$

where $\rho = \int p(\omega)d\omega$ is the mean-square signal. By a similar argument the mean-square value of $s(t+\alpha)$ will be

$$U^2 = \rho \int_0^\infty K^2(t)dt, \tag{25}$$

and the relative error of the prediction may be measured by the ratio of the root-mean-square error to the root-mean-square value of $s(t+\alpha)$, i.e.,

$$\frac{E}{U} = \left[\frac{\int_0^\alpha K^2(t)dt}{\int_0^\infty K^2(t)dt} \right]^{1/2}. \tag{26}$$

The prediction will be relatively poor if the area under the curve $K(t)^2$ out to α is large compared to the total area, good if it is small compared to the total. It is evident from (26) that the relative error starts at zero for $\alpha=0$ and is a monotonic increasing function of α which approaches unity as $\alpha \to \infty$.

There is an important special case in which a great deal more can be shown by the argument just given. In our analysis, the actual problem was replaced by one in which the signal was a Gaussian type of time series, derived from a resistance noise by passing it through a filter with a gain $\sqrt{P(\omega)}$. Suppose the signal is already a time series of this type. Then the error in prediction, due to the tails of impulses occurring between $t=0$ and $t=\alpha$, will have a Gaussian distribution. This follows from the fact that each impulse has a Gaussian distribution of amplitudes and the sum of any number of effects, each Gaussian, will also be Gaussian. The standard deviation of this distribution of errors is just the root-mean-square error E obtained from (24).

Stated another way, on the basis of the available data, that is, $s(t)$ for $t<0$, the future value of the signal $s(t+\alpha)$ is distributed according to a Gaussian distribution. The best linear predictor selects the center of this distribution for the predicted value. The actual future value will differ from this as indicated in Fig. 8, where the future value is plotted horizontally, and the probability density for various values of $s(t+\alpha)$ is plotted vertically.

It is clear that in this special case the linear prediction method is in a sense the best possible. The center of the

Gaussian distribution remains the natural point to choose if we replace the least square criterion of the best prediction by almost any other reasonable criterion, such as the median value or the most probable value. Thus in this case a nonlinear computation would offer nothing which the linear process does not already provide. In the general case, on the other hand, the distribution of future values will not be Gaussian, and the shape of the distribution curve may vary from point to point depending upon the particular past history of the curve. Under these circumstances, a nonlinear scheme may offer improvements upon the linear process and the exact characteristics of the optimal procedure will depend critically upon the criterion adopted for the best prediction.

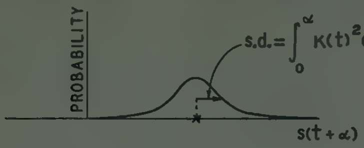

Fig. 8—Distribution of prediction errors in the Gaussian case.

VII. Prediction in the Presence of Noise

Now consider the general prediction and smoothing problem with noise present. The best estimate of $s(t+\alpha)$ is required when the function $s(t)+n(t)$ is known from $t=-\infty$ to the present. If $s(t)+n(t)$ is passed through a filter whose gain is $[P(\omega)+N(\omega)]^{-1/2}$, the result will be a flat spectrum which we can identify with white noise. Let $Y_1(\omega)$ be the transfer function of a filter having this gain characteristic and the associated minimum phase. Then both $Y_1(\omega)$ and the inverse $Y_1^{-1}(\omega)$ are physically realizable networks. Evidently, knowledge of the input of Y_1 and knowledge of its output are equivalent. The best linear operation on the output will give the same prediction as the corresponding best linear operation on the input.

If we knew the entire function $s(t)+n(t)$ from $t=-\infty$ to $t=+\infty$ the best operation to apply to the input of $Y_1(\omega)$ would be that specified by (18). If we let $B(\omega)$ be the phase component of Y_1, this corresponds to the equivalent operation

$$Y_2(\omega) = \frac{P(\omega)}{[P(\omega)+N(\omega)]^{1/2}} e^{i[\alpha\omega - B(\omega)]} \qquad (27)$$

on the "white noise" output of Y_1.

Let the impulse response obtained from (27) be $K_2(t)$. As illustrated by Fig. 9, $K_2(t)$ will, in general, contain tails extending to both $t=+\infty$ and $t=-\infty$, the junction between the two halves of the curve being displaced from the origin by the prediction time α. The associated $K_2(\tau)$ of Fig. 10 is, of course, the ideal weighting function to be applied to the "white noise" output of Y_1. But the only data actually available at $\tau=0$ are the impulses which may be thought of as occurring during the past history of this output. What weights should be given these data to obtain the best

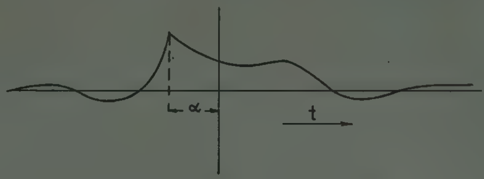

Fig. 9—Possible function $K_2(t)$.

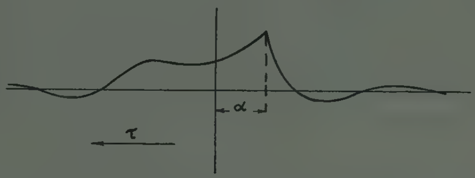

Fig. 10—Weighting function $K_2(\tau)$, corresponding to Fig. 9.

prediction? It seems natural to weight these as one would if all data were available, and to weight the future values zero (as we must to keep the filter physical). The fact that this is actually correct weighting when the various input impulses are statistically independent will now be shown as a consequence of a general statistical principle.

Suppose we have a number of chance variables, $x_1, x_2, \cdots, x_n$ which are statistically independent, or at least have the property that the mean product of any two, $\overline{x_m x_n}$, is equal to zero. These variables are to be interpreted as the amplitudes of the individual white noise impulses to which we are attempting to apply the weighting function of Fig. 10.

Let y be another chance variable, correlated with $x_1, \cdots, x_n$, which we wish to estimate in the least square sense by performing a linear operation on $x_1 \cdots x_n$. In the problem at hand y is the actual signal $s(t)$ at the time α seconds from now.

The predicted value will be

$$y_1 = \sum_{i=1}^{n} a_i x_i$$

and the mean-square error is

$$\begin{aligned} E &= \overline{(y-y_1)^2} = \overline{(y - \sum a_i x_i)^2} \\ &= \overline{y^2} - 2\sum_{i=1}^{n} a_i \overline{x_i y} + \sum_{i,j=1}^{n} a_i a_j \overline{x_i x_j} \\ &= \overline{y^2} - 2\sum a_i \overline{x_i y} + \sum_{i=1}^{n} a_i^2 \overline{x_i^2}, \end{aligned} \qquad (28)$$

since all terms in the double sum vanish except those for which $i=j$. We seek to minimize E by proper choice of the a_i. Setting the partial derivatives with respect to a_i equal to zero, we have

$$\frac{\partial E}{\partial a_i} = -2\overline{x_i y} + 2a_i\overline{x_i^2} = 0$$

or

$$a_i = \frac{\overline{x_i y}}{\overline{x_i^2}}. \qquad (29)$$

The important fact about this calculation is that each of the n minimizing equations involves only the a_1 in question; $\partial E/\partial a_1$ involves only a_1, etc. In other words, minimizing E on all the a_i is equivalent to minimizing separately on the individual a_i; a_1 should have the value $\overline{x_1 y}/\overline{x_1^2}$ whatever values are assigned to the other a's.

Returning now to the prediction and smoothing problem, the function $K_2(\tau)$ gives the proper weighting to be attached to the impulses if we could use them all. Requirements of physical realizability demand that future impulses corresponding to $\tau<0$ be given weight zero. From the above statistical principle those occurring in the past should still be given the weighting $K_2(\tau)$. In other words, the proper filter to apply to the input white noise has an impulse response zero for $t<0$ and $K_2(t)$ for $t>0$.

To summarize, the solution consists of the following steps:

1. Calculate the minimum phase transfer function for the gain $(P+N)^{-1/2}$. Let this be $Y_1(\omega)$.
2. Let

$$Y_2(\omega) = Y_1^{-1}(\omega)\frac{P}{P+N}.$$

This is a nonphysical transfer function. Let its Fourier transform be $K_2(t)$.

3. Set $K_3(t)=K_2(t+\alpha)$ for $t\geqq 0$ and $K_3(t)=0$ for $t<0$. That is, cut off the first α seconds of $K_2(t)$ and shift the remaining tail over to $t=0$. This is the impulse response of a physical network, and is the optimal operation on the past history of the white noise input. Let the corresponding transfer function be $Y_3(\omega)$.
4. Construct $Y_4(\omega)=Y_3(\omega)Y_1(\omega)$. This is the optimal smoothing and prediction filter, as applied to the actual given $s(t)+n(t)$.

As in the pure prediction problem, if the signal and noise happen to be Gaussian time series, the linear prediction is an absolute optimum among all prediction operations, linear or not. Furthermore, the distribution of values of $s(t+\alpha)$, when $f(t)$ is known for $t<0$, is a Gaussian distribution.

VIII. Generalizations

This theory is capable of generalization in several directions. These generalizations will be mentioned only briefly, but can all be obtained by methods similar to those used above.

In the first place, we assumed the true signal and the noise to be uncorrelated. A relatively simple extension of the argument used in Section IV allows one to account for correlation between these time series.

A second generalization is to the case where there are several correlated time series, say $f_1(t), f_2(t), \cdots, f_n(t)$. It is desired to predict, say, $s_1(t+\alpha)$ from a knowledge of $f_1, f_2, \cdots, f_n$.

Finally the desired quantity may not be $s(t+\alpha)$ but, for example, $s'(t+\alpha)$, the future derivative of the true signal. In such a case, one may effectively reduce the problem to that already solved by taking derivatives throughout. The function $f(t)$ is passed through a differentiator to produce $g(t)=f'(t)$. The best linear prediction for $g(t)$ is then determined.

IX. Discussion of the Basic Assumptions

A result in applied mathematics is only as reliable as the assumptions from which it is derived. The theory developed above is especially subject to misapplication because of the difficulty in deciding, in any particular instance, whether the basic assumptions are a reasonable description of the physical situation. Anyone using the theory should carefully consider each of the three main assumptions with regard to the particular smoothing or prediction problem involved.

The assumption that the signal and noise are stationary is perhaps the most innocuous of the three, for it is usually evident from the general nature of the problem when this assumption is violated. The determination of the required power spectra $P(\omega)$ and $N(\omega)$ will often disclose any time variation of the statistical structure of the time series. If the variation is slow compared to the other time constants involved, such nonstationary problems may still be solvable on a quasi-stationary basis. A linear predictor may be designed whose transfer function varies slowly in such a way as to be optimal for the "local" statistics.

The least square assumption is more troublesome, for it involves questions of values rather than questions of fact. When we minimize the mean-square error we are, in effect, paying principal attention to the very large errors. The prediction chosen is one which, on the whole, makes these errors as small as possible, without much regard to relatively minor errors. In many circumstances, however, it is more important to make as many very accurate predictions as possible, even if we make occasional gross errors as a consequence. When the distribution of future events is Gaussian, it does not matter which criterion is used since the most probable event is also the one with respect to which the mean-square error is the least. With lopsided or multimodal distributions, however, a real question is involved.

As a simple example, consider the problem of predicting whether tomorrow will be a clear day. Since clear days are in the majority, and there are no days with negative precipitation to balance days when it rains, we are concerned here with a very lopsided distribution. With such a curve, the average point, which is the one given by a prediction minimizing the mean-square error, might be represented by a day with a light drizzle. To a man planning a picnic, however, such a prediction would have no value. He is interested in the probability that the weather will really be clear. If the picnic must be called off because it in fact rains, the actual amount of precipitation is of comparatively little consequence.

As a second example, consider the problem of intercepting a bandit car attempting to flee down a network of roads. If the road on which the bandit car happens to be forks just ahead, it is clear that a would-be interceptor should station himself on one fork or the other, making the choice at random if necessary. The mean-square error in the interception would be least, however, if he placed himself in the fields beyond the fork. Problems similar to these may also arise in gunnery, where, in general, we are usually interested in the number of actual hits and "a miss is as good as a mile."

The third assumption, that of linearity, is neither a question of fact, nor of evaluation, but a self-imposed limitation on the types of operations or devices to be used in prediction. The mathematical reason for this assumption is clear; linear problems are always much simpler than their nonlinear generalizations. In certain applications the linear assumption may be justified for one or another of the following reasons:

1. The linear predictor may be an absolute optimal method, as in the Gaussian time series mentioned above.

2. Linear prediction may be dictated by the simplicity of mechanization. Linear filters are easy to synthesize and there is an extensive relevant theory, with no corresponding theory for nonlinear systems.

3. One may use the linear theory merely because of the lack of any better approach. An incomplete solution is better than none at all.

How much is lost by restricting ourselves to linear prediction? The fact that nonlinear effects may be important in a prediction can be illustrated by returning to the problem of forecasting tomorrow's weather. We are all familiar with the fact that the pattern of events over a period of time may be more important than the happenings taken individually in determining what will come. For example, the sequence of events in the passage of a cold or warm front is characteristic. Moreover, the significance of a given happening may depend largely upon the intensity with which it occurs. Thus, a sharp dip in the barometer may mean that moderately unpleasant weather is coming. Twice as great a drop in the same time, on the other hand, may not indicate that the weather will be merely twice as unpleasant; it may indicate a hurricane.

As a final point, we may notice that the requirement that the prediction be obtained from a linear device and the objective of minimizing the mean-square error are not, in all problems, quite compatible with one another. The absolute best mean-square prediction (ignoring the assumption of linearity) would, of course, always pick the mean of the future distribution, i.e., the "center of gravity," since in any case this minimizes the mean-square error. In general, however, the position of this center of gravity will be a nonlinear function of the past history. When we require that the prediction be a *linear* operation on the past history, the mathematics is forced to compromise among the conflicting demands of various possible past histories. The compromise amounts essentially to averaging over-all relative phases of the various components of the signal; any pertinent information contained in the relative phases cannot be used properly.

This can be illustrated by the familiar statistical problem of calculating a line or plane of regression to provide a linear least square estimation of one variable y from the knowledge of a set of variables correlated with y.[5] The simplest such problem occurs when there is just one known variable x, and one unknown variable y to be estimated from x. Fig. 11 shows three of the "scatter diagrams" used in statistics. The variable x may be, for example, a man's weight and y his height. A large population is sampled and plotted. It is then desired to

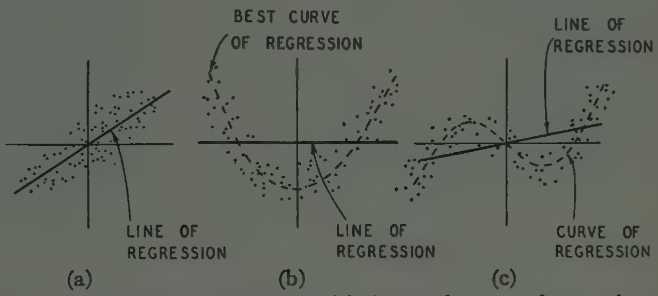

Fig. 11—Some scatter diagrams with lines and curves of regression.

estimate, or predict, a man's height, knowing only his weight. If we agree to use only linear operations y must be calculated in the form $y=ax$. The best choice of a for least square prediction is $\overline{xy}/\overline{x^2}$ and the corresponding straight line is known as the line of regression. The case of a normal distribution corresponds to the Gaussian type noise in which the linear prediction is an absolute optimum.

Figs. 11(b) and 11(c) are scatter diagrams for other distributions of two variables. The lines of regression are now not nearly as good in predicting y as they were in Fig. 11(a). The requirement that the predicted value be a *linear* function of the known data requires a compromise which may be very serious. It is obvious in Figs. 11(b) and 11(c) that a much better estimate of y could be formed if we allowed nonlinear operations on x. In particular, functions of the form ax^2+b and cx^3+dx would be more suitable.

In predicting y from two known variables x_1 and x_2 we can construct a scatter diagram in three dimensions. The linear prediction requires fitting the points with a plane of regression. If there are n known quantities $x_1, x_2, \cdots, x_n$ we need $(n+1)$ dimensional space and the linear theory corresponds to a hyperplane of n dimensions.

The problem of smoothing and prediction for time series is analogous. What we are now dealing with, however, is the function space defined by all the values of $f(t)$ for $t<0$. The optimal linear predictor corresponds to a hyperplane in this function space.

[5] P. G. Hoel, "Introduction to Mathematical Statistics," John Wiley and Sons, Inc., New York, N. Y.; 1947.

Standards on
ELECTRON TUBES: DEFINITIONS OF TERMS, 1950*

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PREFACE

The present *Standards on Electron Tubes: Definitions of Terms*, supersedes Sections 1, 2 and 3 of the *Standards on Electronics: Definitions of Terms, 1938.* Since the issuance of the earlier Standards, the useful frequency range of electron tubes has been extended beyond 10^{10} cycles per second. As the frequency range has been extended upwards, more and more of the high-frequency circuit of necessity has been included within the tube envelope. In addition, the use of electron beams in all types of electron tubes has seen a remarkable growth. These two developments have made necessary the generalization of the familiar electron-tube coefficients so that they apply to all electron tubes, and the drafting of definitions pertaining to electron-beam tubes.

Electron-Tube Admittances

The present Standard generalizes the familiar electron-tube coefficients so that they apply to all types of linear electron-tube transducers at any frequency. The generalizations include the familiar low-frequency concepts. In the case of a triode, for example, at relatively low frequencies the short-circuit input admittance reduces to substantially the grid admittance, the short-circuit output admittance reduces to substantially the plate admittance, the short-circuit forward admittance reduces to substantially the grid-plate transconductance, and the short-circuit feed back admittance reduces to substantially the admittance of the grid-plate capacitance. (Further explanatory material will appear in *Standards on Electron Tubes: Methods of Testing.*)

When reference is made to alternating voltage or current components, the components are understood to be small enough so that linear relations hold between the various alternating voltages and currents.

Consider a generalized network or transducer having n available terminals to each of which is flowing a complex alternating component I_j of the current and between each of which and a reference point (which may or may not be one of the n-network terminals) is applied a complex alternating voltage V_j. In this Standard, this network represents an n-terminal electron tube in which each one of the terminals is connected to an electrode. The terms carrying an asterisk (*) refer to this network.

Electron-Beam Tubes

The present Standard contains a considerable number of definitions of terms which relate to electron tubes in which electron beams are employed. Chart 1 shows the general scheme of classification to which these definitions conform.

General Classification of Radio Beam-Forming Electron Tubes

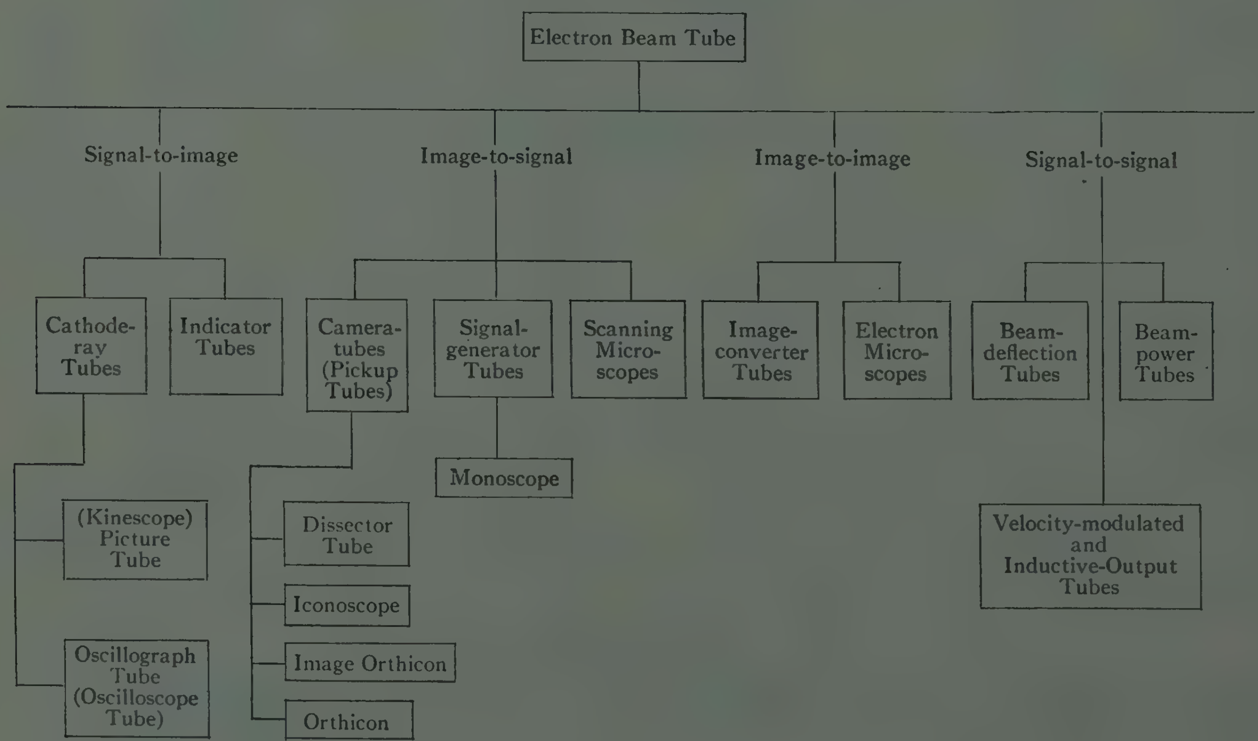

Chart 1

DEFINITIONS

Accelerating Electrode. An electrode to which a potential is applied to increase the velocity of the electrons in the beam.

Accelerating Electrode (of an Electron-Beam Tube). An electrode the potential of which provides an electric field to increase the velocity of the beam electrons.

Admittance.* *See:*
Driving-Point Admittance (between the *j*th Terminal and the Reference Terminal of an *n*-Terminal Network)
Electrode Admittance (of the *j*th Electrode of an *n*-Electrode Electron Tube)
Interelectrode Transadmittance (*j–l* Interelectrode Transadmittance of an *n*-Electrode Electron Tube)*
Short-Circuit Driving-Point Admittance (of the *j*th Terminal of an *n*-Terminal Network)
Short-Circuit Feedback Admittance (of an Electron-Tube Transducer)
Short-Circuit Forward Admittance (of an Electron-Tube Transducer)
Short-Circuit Input Admittance (of an Electron-Tube Transducer)
Short-Circuit Output Admittance (of an Electron-Tube Transducer)
Short-Circuit Transfer Admittance (from the *j*th Terminal to the *l*th Terminal of an *n*-Terminal Network)
Transfer Admittance (from the *j*th Terminal to the *l*th Terminal of an *n*-Terminal Network).

Amplification Factor.* The μ-factor for the plate and control-grid electrodes of an electron tube under the condition that the plate current is held constant.

Amplifier. *See:*
Class-A Amplifier
Class-AB Amplifier
Class-B Amplifier
Class-C Amplifier.

Anode (of an Electron Tube). An electrode through which a principal stream of electrons leaves the interelectrode space.

Anode Breakdown Voltage (of a Glow-Discharge Cold-Cathode Tube). The anode voltage required to cause conduction across the main gap with the starter gap not conducting and with all other tube elements held at cathode potential before breakdown.

Anode Current. *See:* Electrode Current.

Anode Voltage. *See:* Electrode Voltage.

Anode Voltage Drop (of a Glow-Discharge Cold-Cathode Tube). The main gap voltage drop after conduction is established in the main gap.

Astigmatism (Electron Optical). In an electron-beam tube, a focus defect in which electrons in different axial planes come to focus at different points.

Available Conversion Power Gain (of a Conversion Transducer). The ratio of the available output-frequency power from the output terminals of the transducer to the available input-frequency power from the driving generator. (Note—The *maximum available conversion power gain* of a conversion transducer is obtained when the input termination admittance, at input frequency, is the conjugate of the input-frequency driving-point admittance of the conversion transducer.)

Available Power. From a generator or an electric transducer, the power that would be delivered to the output external termination of the generator or transducer if the admittance of the external termination were the conjugate of the output driving-point admittance of the generator or transducer.

Available Power Gain (of an Electric Transducer). The ratio of the available power from the output terminals of the transducer to the available power from the driving generator. (Note—The *maximum available power gain* of an electric transducer is obtained when the input termination admittance is the conjugate of the driving-point admittance at the input terminals of the transducer. It is sometimes called "completely matched power gain.")

Average Electrode Current. The value obtained by integrating the instantaneous electrode current over an averaging time and dividing by the averaging time.

Beam-Deflection Tube. An electron-beam tube in which current in an output circuit is controlled by transverse movement of the electron beam.

Beam-Power Tube. An electron-beam tube in which use is made of directed electron beams to contribute substantially to its power-handling capability, and in which the control grid and the screen grid are essentially aligned.

Camera Tube (Pickup Tube). An electron-beam tube in which an electron-current or charge-density image is formed from an optical image and is scanned in a predetermined sequence to provide an electrical signal.

Capacitance.* *See:*
Electrode Capacitance (of an *n*-Terminal Electron Tube)

* *See:* Preface, Electron-Tube Admittances.

Input Capacitance (of an n-Terminal Electron Tube)
Interelectrode Capacitance (j-lth Interelectrode Capacitance C_{jl} of an n-Terminal Electron Tube)
Output Capacitance (of an n-Terminal Electron Tube)
Short-Circuit Input Capacitance (of an n-Terminal Electron Tube)
Short-Circuit Output Capacitance (of an n-Terminal Electron Tube)
Short-Circuit Transfer Capacitance (of an Electron Tube).

Cathode (of an Electron Tube). An electrode through which a primary stream of electrons enters the interelectrode space.
See also:
Cold Cathode
Hot Cathode (Thermionic Cathode)
Indirectly Heated Cathode (Equipotential Cathode, Unipotential Cathode).

Cathode Current. *See:* Electrode Current.

Cathode Heating Time (of a Gas Tube). The time required for the cathode to attain operating temperature with normal voltage applied to the heating element.

Cathode Heating Time (of a Vacuum Tube). The time required for the time rate of change of the cathode current to reach maximum value. (Note—All electrode voltages are to remain constant during measurement. The tube elements must all be at room temperature at the start of the test.)

Cathode-Ray Tube. An electron-beam tube in which the beam can be focused to a small cross section on a surface and varied in position and intensity to produce a visible pattern.

Characteristic. *See:*
Constant-Current Characteristic
Control Characteristic (of a Gas Tube)
Dynamic Characteristic (of an Electron Tube)
Emission Characteristic
Grid-Drive Characteristic
Load (Dynamic) Characteristic (of an Electron Tube Connected in a Specified Operating Circuit at a Specified Frequency)
Persistence Characteristic (Decay Characteristic) (of a Luminescent Screen)
Spectral Characteristic (of a Luminescent Screen)
Spectral Characteristic (of a Camera Tube)
Static Characteristic (of an Electron Tube)
Transfer Characteristic.

Class-A Amplifier. An amplifier in which the grid bias and alternating grid voltages are such that plate current in a specific tube flows at all times.

Class-AB Amplifier. An amplifier in which the grid bias and alternating grid voltages are such that plate current in a specific tube flows for appreciably more than half but less than the entire electrical cycle.

Class-B Amplifier. An amplifier in which the grid bias is approximately equal to the cutoff value so that the plate current is approximately zero when no exciting grid voltage is applied, and so that plate current in a specific tube flows for approximately one-half of each cycle when an alternating grid voltage is applied.

Class-C Amplifier. An amplifier in which the grid bias is appreciably greater than the cutoff value so that the plate current in each tube is zero when no alternating grid voltage is applied, and so that plate current in a specific tube flows for appreciably less than one-half of each cycle when an alternating grid voltage is applied. (Note—To denote that grid current does not flow during any part of the input cycle, the suffix 1 may be added to the letter or letters of the class identification. The suffix 2 may be used to denote that current flows during some part of the cycle.)

Cold Cathode. A cathode that functions without the application of heat.

Cold-Cathode Tube. An electron tube containing a cold cathode.

Collector. An electrode that collects electrons or ions which have completed their functions within the tube.

Composite Controlling Voltage. The voltage of the anode of an equivalent diode combining the effects of all individual electrode voltages in establishing the space-charge-limited current.

Condensed-Mercury Temperature (of a Mercury-Vapor Tube). By definition, the temperature measured on the outside of the tube envelope in the region where the mercury is condensing in a glass tube or at a designated point on a metal tube.

Conductance. *See:*
Conductance for Rectification
Conversion Transconductance (of a Heterodyne Conversion Transducer)
Electrode Conductance*
Interelectrode Transconductance (j-l Interelectrode Transconductance)*

Conductance for Rectification. The quotient of the electrode alternating current of low frequency by the in-phase component of the electrode alternating voltage of low frequency, a high-frequency sinusoidal voltage being applied to the same or another electrode and all other electrode voltages being maintained constant.

* *See:* Preface, Electron-Tube Admittances.

Constant-Current Characteristic. The relation, usually represented by a graph, between the voltages of two electrodes, with the current to one of them as well as all other voltages maintained constant.

Control Characteristic (of a Gas Tube). A relation, shown by a graph, between critical grid voltage and anode voltage.

Control Electrode. An electrode on which a voltage is impressed to vary the current flowing between two or more other electrodes.

Control Grid. A grid, ordinarily placed between the cathode and an anode, for use as a control electrode.

Control Ratio (of a Gas Tube). The ratio of the change in anode voltage to the corresponding change in critical grid voltage, with all other operating conditions maintained constant.

Conversion Transconductance (of a Heterodyne Conversion Transducer). The quotient of the magnitude of the desired output-frequency component of current by the magnitude of the input-frequency (signal) component of voltage when the impedance of the output external termination is negligible for all of the frequencies which may affect the result. (Note—Unless otherwise stated, the term refers to the cases in which the input-frequency voltage is of infinitesimal magnitude. All direct electrode voltages and the magnitude of the local-oscillator voltage must remain constant.)

Conversion Transducer. An electric transducer in which the input and the output frequencies are different. (Note—If the frequency-changing property of a conversion transducer depends upon a generator of frequency different from that of the input or output frequencies, the frequency and voltage or power of this generator are parameters of the conversion transducer.)

Conversion Voltage Gain (of a Conversion Transducer). The ratio of (1) the magnitude of the output-frequency voltage across the output termination, with the transducer inserted between the input-frequency generator and the output termination, to (2) the magnitude of the input-frequency voltage across the input termination of the transducer.

Converter Tube. An electron tube that combines the mixer and local-oscillator functions of a heterodyne conversion transducer.

Critical Grid Current. In a gas tube, the instantaneous value of grid current when the anode current starts to flow.

Critical Grid Voltage. In a gas tube, the instantaneous value of grid voltage at which the anode current starts to flow.

Current. *See:*
Average Electrode Current
Critical Grid Current
Electrode Current (of an Electron Tube)
Fault Electrode Current (Surge Electrode Current)
Field-Free Emission Current (of a Cathode)
Gas (Ionization) Current (in a Vacuum Tube)
Heater Current
Inflection-Point Emission Current
Inverse Electrode Current
Peak Cathode Current (Steady-State)
Peak Electrode Current
Transfer Current (of a Glow-Discharge Cold-Cathode Tube).

Cutoff Voltage (of an Electron Tube). That electrode voltage which reduces the value of the dependent variable of an electron tube characteristic to a specified low value. (Note—A specific cutoff characteristic should be identified as follows: current versus grid cutoff voltage, spot brightness versus grid cutoff voltage, etc.)

Decay Characteristic. *See:* Persistence Characteristic.

Decelerating Electrode (of an Electron-Beam Tube). An electrode the potential of which provides an electric field to decrease the velocity of the beam electrons.

Deflecting Electrode. An electrode the potential of which provides an electric field to produce deflection of an electron beam.

Deflecting Yoke. An assembly of one or more coils the current through which provides a magnetic field to produce deflection of an electron beam.

Deflection Factor (of a Cathode-Ray Tube). The reciprocal of the deflection sensitivity.

Deflection Sensitivity (of a Cathode-Ray Oscillograph Tube). The quotient of the displacement of the electron beam at the place of impact by the change in the deflecting field. (Note—Deflection sensitivity is usually expressed in millimeters per volt applied between the deflecting electrodes or in millimeters per gauss of the deflecting magnetic field.)

Deflection Sensitivity (of an Electrostatic-Deflection Cathode-Ray Tube). The quotient of the spot displacement by the change in deflecting potential.

Deflection Sensitivity (of a Magnetic-Deflection Cathode-Ray Tube). The quotient of the spot displacement by the change in deflecting magnetic field.

Deflection Sensitivity (of a Magnetic-Deflection Cathode-Ray Tube and Yoke Assembly). The quotient of the spot displacement by the change in deflecting-coil current.

* *See:* Preface, Electron-Tube Admittances.

Deionization Time (of a Gas Tube). The time required for the grid to regain control after anode-current interruption. (Note—To be exact, the ionization and deionization times of a gas tube should be presented as families of curves relating such factors as condensed-mercury temperature, anode and grid currents, anode and grid voltages, and regulation of the grid current.)

Diode. A two-electrode electron tube containing an anode and a cathode.
See also: Equivalent Diode.

Diode Characteristic (of a Multielectrode Tube). The composite electrode characteristic taken with all electrodes except the cathode connected together.

Direct Grid Bias. The direct component of grid voltage (Note—This is commonly called grid bias.)

Dissector Tube. A camera tube having a continuous photocathode on which is formed a photoelectric-emission pattern which is scanned by moving its electron-optical image over an aperture.

Driving-Point Admittance (between the *j*th Terminal and the Reference Terminal of an *n*-Terminal Network).* The quotient of the complex alternating component I_j of the current flowing to the jth terminal from its external termination by the complex alternating component V_j of the voltage applied to the jth terminal with respect to the reference point when all other terminals have arbitrary external terminations. (Note—In specifying the driving-point admittance of a given pair of terminals of a network or transducer having two or more pairs of terminals, no two pairs of which contain a common terminal, all other pairs of terminals are connected to arbitrary admittances.)

Dynamic Characteristic (of an Electron Tube). *See:* Load Characteristic (of an Electron Tube).

Dynode (of an Electron Tube). An electrode whose primary function is to alter by secondary-electron emission the electron current to itself or to other electrodes.

Dynode Current. *See:* Electrode Current.

Electrode (of an Electron Tube). A conducting element that performs one or more of the functions of emitting, collecting, or controlling by an electric field the movements of electrons or ions.
See also:
Accelerating Electrode
Accelerating Electrode (of an Electron-Beam Tube)
Anode (of an Electron Tube)
Control Electrode
Decelerating Electrode (of an Electron-Beam Tube)
Deflecting Electrode
Electrode Characteristic
Focusing Electrode
Intensifier Electrode
Modulating Electrode
Signal Electrode (of a Camera Tube).

Electrode Admittance (of the *j*th Electrode of an *n*-Electrode Electron Tube).* The short-circuit driving-point admittance between the jth electrode and the reference point measured directly at the jth electrode. (Note—To be able to determine the intrinsic electronic merit of an electron tube the driving-point and transfer admittances must be defined as if measured directly at the electrodes inside the tube. The definitions of Electrode Admittance and Electrode Impedance are included for this reason.)

Electrode Capacitance (of an *n*-Terminal Electron Tube).* The capacitance determined from the short-circuit driving-point admittance at that electrode.

Electrode Characteristic. A relation, usually shown by a graph, between the electrode voltage and the current of an electrode, all other electrode voltages being maintained constant.

Electrode Conductance.* The real part of the electrode admittance.

Electrode Current (of an Electron Tube). The current passing to or from an electrode through the interelectrode space. (Note—The terms cathode current, grid current, anode current, plate current, etc., are used to designate electrode currents for these specific electrodes. Unless otherwise stated, an electrode current is measured at the available terminal.)

Electrode-Current Averaging Time. The time interval over which the current is averaged in defining the operating capabilities of the electrode.

Electrode Dissipation. The power dissipated in the form of heat by an electrode as a result of electron and/or ion bombardment.

Electrode Impedance.* The reciprocal of the electrode admittance.

Electrode Resistance.* The reciprocal of the electrode conductance. (Note—This is the effective parallel resistance and is not the real component of the electrode impedance.)

Electrode Voltage. The voltage between an electrode and the cathode or a specified point of a filamentary cathode. (Note—The terms grid voltage, anode voltage, plate voltages, etc., are used to designate the voltage between these specific electrodes and the cathode. Unless otherwise stated, electrode voltages are understood to be measured at the available terminals.)

* *See:* Preface, Electron-Tube Admittances.

Electrometer Tube. A high-vacuum tube having a very low control-electrode conductance to facilitate the measurement of extremely small direct current or voltage.

Electron-Beam Tube. An electron tube the performance of which depends upon the formation and control of one or more electron beams.

Electron Device. A device in which conduction by electrons takes place through a vacuum, gas, or semiconductor.

Electron Emission. The liberation of electrons from an electrode into the surrounding space. Quantitatively, it is the rate at which electrons are emitted from an electrode.

Electron Gun. An electrode structure which produces and may control, focus, and deflect an electron beam.

Electron Tube. An electron device in which conduction by electrons takes place through a vacuum or gaseous medium within a gas-tight envelope.

Electronic. Of or pertaining to devices, circuits, or systems utilizing electron devices. *Examples:* Electronic control, electronic equipment, electronic instrument and electronic circuit.

Electronics. That field of science and engineering which deals with electron devices and their utilization.

Electronics, used as an adjective, signifies of or pertaining to the field of electronics. *Examples:* Electronics engineer, electronics course, electronics laboratory and electronics committee.

Electrostatic Focusing. A method of focusing an electron beam by the action of an electric field.

Element (of an Electron Tube). Any integral part of the tube that contributes to its operation.

Emission Characteristic. A relation, usually shown by a graph, between the emission and a factor controlling the emission (such as temperature, voltage, or current of the filament or heater).

Equivalent Diode. The imaginary diode consisting of the cathode of a triode or multigrid tube and a virtual anode to which is applied a composite controlling voltage such that the cathode current is the same as in the triode or multigrid tube.

External Termination (of the *j*th Terminal of an *n*-Terminal Network).* That passive or active two-terminal network which is attached externally between the *j*th terminal and the reference point.

Factor. *See:*
Deflection Factor (of a Cathode-Ray Tube)
μ-factor (of an n-Terminal Electron Tube)
Rectification Factor
Transrectification Factor.

Fault Electrode Current (Surge Electrode Current). The peak current that flows through an electrode under fault conditions, such as arc backs and load short circuits.

Field-Free Emission Current (of a Cathode). The electron current drawn from the cathode when the electric gradient at the surface of the cathode is zero.

Filament. A cathode of a thermionic tube, usually in the form of a wire or ribbon, to which heat may be supplied by passing current through it. This is also known as a filamentary cathode.

Filament Current. Current supplied to a filament to heat it.

Filament Voltage. The voltage between the terminals of a filament.

Flexion-Point Emission Current. That value of current on the diode characteristic for which the second derivative of the current with respect to the voltage has its maximum negative value. This current corresponds to the upper flexion point of the diode characteristic and is an approximate measure of the temperature-limited emission current.

Focusing. The process of controlling the convergence and divergence of an electron beam.
See also:
Electrostatic Focusing
Gas Focusing
Magnetic Focusing.

Focusing Coil or Focusing Magnet. An assembly producing a magnetic field for focusing an electron beam.

Focusing Electrode. An electrode to which a potential is applied to control the cross-sectional area of the electron beam.

Gain. *See:*
Available Conversion Power Gain (of a Conversion Transducer)
Available Power Gain (of an Electric Transducer)
Insertion Power Gain (of an Electric Transducer)
Insertion Voltage Gain (of an Electric Transducer)
Conversion Voltage Gain (of a Conversion Transducer).

Gap. *See:*
Main Gap (of a Glow-Discharge Cold-Cathode Tube)
Starter Gap (of a Glow-Discharge Cold-Cathode Tube).

Gas (Ionization) Current (in a Vacuum Tube). Current flowing to a negatively biased electrode and composed

* *See:* Preface, Electron-Tube Admittances.

of positive ions which are produced by an electron current flowing between other electrodes. Positive ions are a result of collision between electrons and molecules of the residual gas.

Gas Focusing. A method of concentrating an electron beam by the action of ionized gas.

Gas Ratio. The ratio of the ion current in a tube to the electron current that produces it.

Gas Tube. An electron tube in which the pressure of the contained gas or vapor is such as to affect substantially the electrical characteristics of the tube.

Glow Discharge. A discharge of electricity through a gas, characterized by a space potential in the vicinity of the cathode that is much higher than the ionization potential of the gas.

Glow-Discharge Cold-Cathode Tube. A gas tube that depends for its operation on the properties of a glow discharge.

Grid. An electrode having one or more openings for the passage of electrons or ions.

See also:
Control Grid
Screen Grid
Space-Charge Grid
Suppressor Grid.

Grid Bias. *See:* Direct Grid Bias.

Grid Characteristic. *See:* Electrode Characteristic.

Grid Current. *See:* Electrode Current.

Grid-Drive Characteristic. A relation, usually shown by a graph, between electrical or light output and control-electrode voltage measured from cutoff.

Grid Driving Power. The average product of the instantaneous values of the grid current and of the alternating component of the grid voltage over a complete cycle. (Note—This comprises the power supplied to the biasing device and to the grid.)

Grid Emission. Electron or ion emission from a grid of an electron tube.

Grid Voltage. *See:* Electrode Voltage.

Harmonic Conversion Transducer (Frequency Multiplier, Frequency Divider). A conversion transducer in which the output signal frequency is a multiple or submultiple of the input frequency. (Note—In general, the output signal amplitude is a nonlinear function of the input signal amplitude.)

Heater. An electric heating element for supplying heat to an indirectly heated cathode.

Heater Current. The current flowing through a heater.

Heater Voltage. The voltage between the terminals of a heater.

Heptode. A seven-electrode electron tube containing an anode, a cathode, a control electrode, and four additional electrodes that are ordinarily grids.

Heterodyne Conversion Transducer (Converter). A conversion transducer in which the output frequency is the sum or difference of the input frequency and an integral multiple of a local oscillator frequency. (Note—The frequency and voltage or power of the local oscillator are parameters of the conversion transducer. Ordinarily, the output signal amplitude is a linear function of the input signal amplitude over its useful operating range.)

Hexode. A six-electrode electron tube containing an anode, a cathode, a control electrode, and three additional electrodes that are ordinarily grids.

Hot Cathode (Thermionic Cathode). A cathode that functions primarily by the process of thermionic emission.

Hot-Cathode Tube. An electron tube containing a hot cathode.

Iconoscope. A camera tube in which a high-velocity electron beam scans a photoactive mosaic that has electrical storage capability.

Image Orthicon. A camera tube in which an electron image is produced by a photoemitting surface and focused on a separate storage target, which is scanned on its opposite side by a low-velocity electron beam.

Indicator Tube. An electron-beam tube in which useful information is conveyed by the variation in cross section of the beam at a luminescent target.

Indirectly Heated Cathode (Equipotential Cathode, Unipotential Cathode). A cathode of a thermionic tube to which heat is supplied by an independent heater element.

Inflection-Point Emission Current. That value of current on the diode characteristic for which the second derivative of the current with respect to the voltage is zero. This current corresponds to the inflection point of the diode characteristic and is an approximate measure of the maximum space-charge-limited emission current.

Input Capacitance (of an n-Terminal Electron Tube).* The short-circuit transfer capacitance between the input terminal and all other terminals, except the output terminal, connected together. (Note—This quantity is equivalent to the sum of the interelectrode capacitances between the input electrode and all other electrodes except the output electrode.)

* *See:* Preface, Electron-Tube Admittances.

Insertion Power Gain (of an Electric Transducer). The ratio of (1) the power developed in the external termination of the output with the transducer inserted between generator and output termination to (2) the power developed in the external termination of the output with the generator connected directly to the output termination.

Insertion Voltage Gain (of an Electric Transducer). The complex ratio of (1) the alternating component of voltage across the external termination of the output with the transducer inserted between the generator and the output termination to (2) the voltage across the external termination of the output when the generator is connected directly to the output termination.

Intensifier Electrode. A post-accelerating electrode.

Interelectrode Capacitance (*j-l*th Interelectrode Capacitance C_{jl} of an *n*-Terminal Electron Tube).* The capacitance determined from the short-circuit transfer admittance between the *j*th and the *l*th terminals. (Note—This quantity is often referred to as direct interelectrode capacitance.)

Interelectrode Transadmittance (*j-l* Interelectrode Transadmittance of an *n*-Electrode Electron Tube).* The short-circuit transfer admittance from the *j*th electrode to the *l*th electrode.

Interelectrode Transconductance (*j-l* Interelectrode Transconductance).* The real part of the *j-l* interelectrode transadmittance.

Internal Correction Voltage (of an Electron Tube). The voltage that is added to the composite controlling voltage and is the voltage equivalent of such effects as those produced by initial electron velocity and contact potential.

Inverse Electrode Current. The current flowing through an electrode in the direction opposite to that for which the tube is designed.

Ion Spot (on a Cathode-Ray-Tube Screen). An area of localized deterioration of luminescence caused by bombardment with negative ions.

Ionic-Heated Cathode. A hot cathode that is heated primarily by ionic bombardment of the emitting surface.

Ionic-Heated Cathode Tube. An electron tube containing an ionic-heated cathode.

Ionization Current. *See:* Gas Current.

Ionization Time (of a Gas Tube). The time interval between the initiation of conditions for and the establishment of conduction at some stated value of tube voltage drop.

Line or Trace. The path of a moving spot.

Load (Dynamic) Characteristic (of an Electron Tube Connected in a Specified Operating Circuit, at a Specified Frequency). A relation, usually represented by a graph, between the instantaneous values of a pair of variables such an electrode voltage and current, when all direct electrode supply voltages are maintained constant.

Local Oscillator Tube. An electron tube in a heterodyne conversion transducer to provide the local heterodyning frequency for a mixer tube.

Magnetic Focusing. A method of focusing an electron beam by the action of a magnetic field.

Main Gap (of a Glow-Discharge Cold-Cathode Tube). The conduction path between a principal cathode and a principal anode.

Mercury-Vapor Tube. A gas tube in which the active gas is mercury vapor.

Microphonism (Microphonics) (in an Electron Tube). The modulation of one or more of the electrode currents resulting from the mechanical vibration of a tube element.

Mixer Tube. An electron tube that performs only the frequency-conversion function of a heterodyne conversion transducer when it is supplied with voltage or power from an external oscillator.

Modulating Electrode. An electrode to which a potential is applied to control the magnitude of the beam current.

Monoscope. A signal generating electron-beam tube in which a picture signal is produced by scanning an electrode, parts of which have different secondary-emission characteristics.

μ-Factor (of an *n*-Terminal Electron Tube).* The ratio of the magnitude of infinitesimal change in the voltage at the *j*th electrode to the magnitude of an infinitesimal change in the voltage at an *l*th electrode under the conditions that the current to the *m*th electrode remains unchanged, and the voltages of all other electrodes be maintained constant.

Multielectrode Tube. An electron tube containing more than three electrodes associated with a single electron stream.

Multiple-Unit Tube. An electron tube containing within one envelope two or more groups of electrodes associated with independent electron streams. (Note—A multiple-unit tube may be so indicated; for example, duodiode, duotriode, diode-pentode, duodiode-triode, duodiode-pentode, and triode-pentode.)

Octode. An eight-electrode electron tube containing an anode, a cathode, a control electrode, and five additional electrodes that are ordinarily grids.

* *See:* Preface, Electron-Tube Admittances.

Operating Characteristic. *See:* Load Characteristic.

Orthicon. A camera tube in which a low-velocity electron beam scans a photoactive mosaic that has electrical storage capability.

Oscillograph Tube (Oscilloscope Tube). A cathode-ray tube used to produce a visible pattern, which is the graphical representation of electrical signals, by variations of the position of the focused spot or spots in accordance with these signals.

Output Capacitance (of an n-Terminal Electron Tube).* The short-circuit transfer capacitance between the output terminal and all other terminals, except the input terminal, connected together.

Peak Cathode Current (Steady-State). The maximum instantaneous value of a periodically recurring cathode current.

Peak Electrode Current. The maximum instantaneous current that flows through an electrode.

Peak Forward Anode Voltage. The maximum instantaneous anode voltage in the direction in which the tube is designed to pass current.

Peak Inverse Anode Voltage. The maximum instantaneous anode voltage in the direction opposite to that in which the tube is designed to pass current.

Pentode. A five-electrode electron tube containing an anode, a cathode, a control electrode, and two additional electrodes that are ordinarily grids.

Persistence Characteristic (Decay Characteristic) (of a Luminescent Screen). A relation, usually shown by a graph, between emitted radiant power and time after excitation.

Perveance. The quotient of the space-charge-limited cathode current by the three-halves power of the anode voltage in a diode. (Note—Perveance is the constant G appearing in the Child-Langmuir-Schottky equation

$$i_k = Ge_b^{3/2}.$$

When the term perveance is applied to a triode or multigrid tube, the anode voltage e_b is replaced by the composite controlling voltage e' of the equivalent diode.)

Phosphor. A substance capable of luminescence.

Phototube. An electron tube in which one of the electrodes is irradiated for the purpose of causing electron emission.

Picture Tube (Kinescope). A cathode-ray tube used to produce an image by variation of the beam intensity as the beam scans a raster.

Plate. A common name for the principal anode in an electrode tube.

Plate Characteristic. *See:* Electrode Characteristic.

Plate Current. *See:* Electrode Current.

Plate Voltage. *See:* Electrode Voltage.

Post-Acceleration (in an Electron-Beam Tube). Acceleration of the beam electrons after deflection.

Power. *See:*
Available Power
Grid Driving Power.

Raster. A predetermined pattern of scanning lines which provides substantially uniform coverage of an area.

Rectification Factor. The quotient of the change in average current of an electrode by the change in amplitude of the alternating sinusoidal voltage applied to the same electrode, the direct voltages of this and other electrodes being maintained constant.

Regulation (of a Glow-Discharge Cold-Cathode Tube). The difference between the maximum and minimum anode voltage drop over a range of anode current.

Screen (of a Cathode-Ray Tube). The surface of the tube upon which the visible pattern is produced.

Screen Grid. A grid placed between a control grid and an anode, and usually maintained at a fixed positive potential, for the purpose of reducing the electrostatic influence of the anode in the space between the screen grid and the cathode.

Screen-Grid Characteristic. *See:* Electrode Characteristic.

Screen-Grid Current. *See:* Electrode Current.

Secondary Emission. Electron emission from solids or liquids resulting directly from bombardment of their surfaces by electrons or ions.

Secondary Grid Emission. Electron emission from a grid resulting directly from bombardment of its surface by electrons or other charged particles.

Sensitivity (of a Camera Tube). The signal current developed per unit incident radiation density, (i.e., per watt per unit area). Unless otherwise specified, the radiation is understood to be that of an unfiltered incandescent source of 2870°K, and its density, which is generally measured in watts per unit area, may then be expressed in foot-candles.

Short-Circuit Driving-Point Admittance (of the jth Terminal of an n-Terminal Network).* The driving-point admittance between that terminal and the refer-

* *See:* Preface, Electron-Tube Admittances

ence terminal when all other terminals have zero alternating components of voltage with respect to the reference point.

Short-Circuit Feedback Admittance (of an Electron-Tube Transducer).* The short-circuit transfer admittance from the physically available output terminals to the physically available input terminals of a specified socket, associated filters, and tube.

Short-Circuit Forward Admittance (of an Electron-Tube Transducer).* The short-circuit transfer admittance from the physically available input terminals to the physically available output terminals of a specified socket, associated filters, and tube.

Short-Circuit Input Admittance (of an Electron-Tube Transducer).* The short-circuit driving-point admittance at the physically available input terminals of a specified socket, associated filters, and electron tube.

Short-Circuit Input Capacitance (of an n-Terminal Electron Tube).* The effective capacitance determined from the short-circuit input admittance.

Short-Circuit Output Admittance (of an Electron-Tube Transducer).* The short-circuit driving-point admittance at the physically available output terminals of a specified socket, associated filters, and tube.

Short-Circuit Output Capacitance (of an n-Terminal Electron Tube).* The effective capacitance determined from the short-circuit output admittance.

Short-Circuit Transfer Admittance (from the jth Terminal to the lth Terminal of an n-Terminal Network).* The transfer admittance from terminal j to terminal l when all terminals except j have zero complex alternating components of voltage with respect to the reference point.

Short-Circuit Transfer Capacitance (of an Electron Tube).* The effective capacitance determined from the short-circuit transfer admittance.

Signal Electrode (of a Camera Tube). An electrode from which the signal output is obtained.

Space-Charge Grid. A grid, usually positive, that controls the position, area, and magnitude of a potential minimum or of a virtual cathode in a region adjacent to the grid.

Spectral Characteristic (of a Luminescent Screen). A relation, usually shown by a graph, between wavelength and emitted radiant power per unit wavelength interval.

Spectral Characteristic (of a Camera Tube). A relation, usually shown by a graph, between wavelength and sensitivity per unit wavelength interval.

Spot. The area instantaneously affected by the impact of an electron beam.
See also: Ion Spot (on a Cathode-Ray-Tube Screen).

Starter (of a Glow-Discharge Cold-Cathode Tube). An auxiliary electrode used to initiate conduction.

Starter Breakdown Voltage (of a Glow-Discharge Cold-Cathode Tube). The starter voltage required to cause conduction across the starter gap with all other tube elements held at cathode potential before breakdown.

Starter Gap (of a Glow-Discharge Cold-Cathode Tube). The conduction path between a starter and the other electrode to which starting voltage is applied.

Starter Voltage Drop (of a Glow-Discharge Cold-Cathode Tube). The starter-gap voltage drop after conduction is established in the starter gap.

Static Characteristic (of an Electron Tube). A relation usually represented by a graph, between a pair of variables such as electrode voltage and electrode current, with all other voltages maintained constant.

Suppressor Grid. A grid that is interposed between two positive electrodes (usually the screen grid and the plate), primarily to reduce the flow of secondary electrons from one electrode to the other.

Surge Electrode Current. The recommended term is Fault Electrode Current.

Tetrode. A four-electrode electron tube containing an anode, a cathode, a control electrode, and one additional electrode that is ordinarily a grid.

Thermionic Cathode. *See:* Hot Cathode.

Thermionic Emission. Electron or ion emission due to the temperature of the emitter.

Thermionic Grid Emission (Primary Grid Emission) Current produced by electrons thermionically emitted from a grid.

Thermionic Tube. An electron tube in which one of the electrodes is heated for the purpose of causing electron or ion emission from that electrode.

Thyratron. A hot-cathode gas tube in which one or more control electrodes initiate, but do not limit, the anode current except under certain operating conditions.

Transadmittance.* *See:* Interelectrode Transadmittance.

Transconductance.* As most commonly used, the interelectrode transconductance between the control grid and the plate. At low frequencies, transconductance is the slope of the control-grid-to-plate transfer characteristic.

* *See:* Preface, Electron-Tube Admittances.

Transducer. *See:*
Conversion Transducer
Harmonic Conversion Transducer (Frequency Multiplier, Frequency Divider)
Heterodyne Conversion Transducer (Converter).

Transfer Admittance (from the jth Terminal to the lth Terminal of an n-Terminal Network).* The quotient of the complex alternating component I_l of the current flowing to the lth terminal from the lth external termination by the complex alternating component V_j of the voltage applied to the jth terminal with respect to the reference point when all other terminals have arbitrary external terminations.

Transfer Characteristic. A relation, usually shown by a graph, between the voltage of one electrode and the current to another electrode, all other electrode voltages being maintained constant.

Transfer Current (of a Glow-Discharge Cold-Cathode Tube). The starter-gap current required to cause conduction across the main gap. (Note—The transfer current is a function of the anode voltage.)

Transrectification Factor. The quotient of the change in average current of an electrode by the change in the amplitude of the alternating sinusoidal voltage applied to another electrode, the direct voltages of this and other electrodes being maintained constant. (Note—Unless otherwise stated, the term refers to cases in which the alternating sinusoidal voltage is of infinitesimal magnitude.)

Triode. A three-electrode electron tube containing an anode, a cathode, and a control electrode.

Tube. *See:*
Beam-Deflection Tube
Beam-Power Tube
Camera Tube (Pickup Tube)
Cathode-Ray Tube
Cold-Cathode Tube
Converter Tube
Dissector Tube
Electrometer Tube
Electron-Beam Tube
Electron Tube
Gas Tube
Glow-Discharge Cold-Cathode Tube
Hot-Cathode Tube
Iconoscope
Image Orthicon
Indicator Tube
Ionic-heated Cathode Tube
Local Oscillator Tube
Mercury-Vapor Tube
Mixer Tube
Monoscope
Multielectrode Tube
Multiple-Unit Tube
Orthicon
Oscillograph Tube (Oscilloscope Tube)
Picture Tube (Kinescope)
Phototube
Thermionic Tube
Thyratron
Vacuum Tube
Variable-mu Tube

Tube Heating Time (in a Mercury-Vapor Tube). The time required for the coolest portion of the tube to attain operating temperature.

Tube Voltage Drop. The anode voltage during the conducting period.

Vacuum Tube. An electron tube evacuated to such a degree that its electrical characteristics are essentially unaffected by the presence of residual gas or vapor.

Variable-mu Tube. An electron tube in which the amplification factor varies in a predetermined way with control-grid voltage.

Voltage. *See:*
Anode Breakdown Voltage (of a Glow-Discharge Cold-Cathode Tube)
Anode Voltage Drop (of a Glow-Discharge Cold-Cathode Tube)
Composite Controlling Voltage
Critical Grid Voltage
Cutoff Voltage (of an Electron Tube)
Electrode Voltage
Heater Voltage
Internal Correction Voltage (of an Electron Tube)
Peak Forward Anode Voltage
Peak Inverse Anode Voltage
Starter Voltage Drop (of a Glow-Discharge Cold-Cathode Tube)
Tube Voltage Drop

* *See:* Preface, Electron-Tube Admittances.

Contributors to the Proceedings of the I.R.E.

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James S. Allen

In 1939, Dr. Allen joined the faculty of the physics department of Kansas State College as associate professor. During the early part of the war, he was a staff member at the MIT Radiation Laboratory and helped develop the indicator systems used in radar. After leaving the Radiation Laboratory, he joined the Los Alamos Laboratory.

From 1946 to 1948, Dr. Allen was assistant professor of physics in the department of physics, and also in the Institute for Nuclear Studies at the University of Chicago. In 1948, he joined the faculty of the department of physics at the University of Illinois as associate professor.

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Henry G. Booker (SM'45) was born at Barking, Essex, England, in 1910. He was educated at Cambridge University, where he received the B.A. degree in 1933 and the Ph.D. degree in 1936. He was awarded the Smith's Prize in 1935 and became a Research Fellow of Christ's College in the same year.

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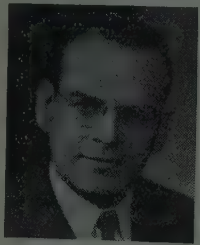
From July, 1937, to July, 1938, he was a visiting scientist at the Department of Terrestrial Magnetism of the Carnegie Institution of Washington. During the war he was in charge of theoretical research at the Telecommunications Research Establishment in England, and was decorated by the U. S. Government. After the war he returned to Cambridge University as a lecturer, and in 1948 became a professor of electrical engineering at Cornell University.

Dr. Booker is an associate member of the Institution of Electrical Engineers, London, by which institution he was awarded the Duddell Premium in 1946 and the Institution Premium in 1947. He is vice-chairman of the IRE Wave-Propagation Committee and of certain commissions associated with the International Scientific Radio Union; and is a member of a panel of the Research and Development Board.

Stuart L. Bailey (A'28–M'36–SM'43–F'43) was born in Minneapolis, Minn., on October 7, 1905. He received the B.S.E.E. degree from the University of Minnesota in 1927, and the M.S. degree from the same institution in 1928.



S. L. Bailey

In the summer of 1928, Mr. Bailey became assistant radio engineer with the airways division of the United States Department of Commerce, where he worked on radio aids to marine and air navigation. Following a year in Panama, during which he installed two automatic marine radio beacons there, Mr. Bailey joined with C. M. Jansky, Jr., to form the consulting engineering firm of Jansky and Bailey, in September, 1930. Mr. Bailey's activities in the consulting field have been on both general allocation problems and specific engineering guidance for broadcast stations and commercial operating companies. He has had charge of all laboratory activities of the firm, as well as all government-contract work done by Jansky and Bailey during World War II. Mr. Bailey has been active in the development of frequency-modulation broadcasting, supervising the technical operations of radio station W3XO, an experimental FM broadcasting station operated by Jansky and Bailey from 1938 to 1945.

Mr. Bailey was President of the IRE in 1949, and has served as a member of the Board of Directors since 1943 and on the Executive Committee since 1945. He was appointed Treasurer of the Institute in 1948. He is a member of Sigma Xi, Tau Beta Pi, and Eta Kappa Nu.

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Gilbert B. Devey (S'45–A'48–M'48) was born on January 5, 1921, in Swissvale, Pa. After a war-interrupted college course at the Carnegie Institute of Technology, he was awarded the S.B. degree by the Massachusetts Institute of Technology in June, 1946.

Gilbert B. Devey

From June, 1941, until December, 1945, Mr. Devey served with the U. S. Navy. He was radar and airborne electronics officer on the *U.S.S. Saratoga* from April, 1942, until October, 1944. From November, 1944, until November, 1945, he attended a course in electronics engineering, Postgraduate School, U. S. Naval Academy. In December, 1945, he was separated from active duty with the rank of lieutenant commander.

During the period from July, 1946, to November, 1947, Mr. Devey was an electronics engineer with the Bureau of Ships. From November, 1947, until April, 1949, he held the position of antenna engineering supervisor at the U. S. Navy Underwater Sound Laboratory, New London, Conn., specializing in antenna systems for submarines. In April, 1949, he joined the Undersea Warfare Branch of the Office of Naval Research, where he now is concerned with problems in electronics peculiar to the complexities of the undersea warfare situation. Mr. Devey is currently serving on the steering and program committees of the IRE/AIEE/RMA "Symposium on Improved Quality Electronic Components."

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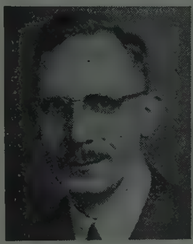
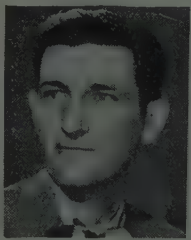
Hendrik W. Bode (M'31–SM'43) was born on December 24, 1905, in Madison, Wis. He obtained the A.B. degree from Ohio State University in 1924 and the Ph.D. degree in physics from Columbia University in 1935. Since 1926 he has been a member of the technical staff of the Bell Telephone Laboratories, engaged in research in network theory and other fields of applied mathematics.



H. W. Bode

❖

W. E. Gordon (A'46–M'49) was born in Paterson, N. J., on January 8, 1918. He received the B.A. degree from Montclair in 1939, and the M.S. degree in meteorology from New York University in 1946. During World War II he served with the Air Weather Services, and was associated with research on radar range forecasting and microwave propagation in the lower atmosphere at the MIT Radiation Laboratory, and with the Committee on Propagation of the National Defense Research Council. In 1945 he joined the Electrical Engineering Research Laboratory at the University of Texas as a meteorologist, and became associate director of that Laboratory in 1946.



W. E. Gordon

In 1948 he accepted a position as research associate at Cornell University, working in radio astronomy and, more recently, supervising a research project on tropospheric propagation.

Mr. Gordon is a member of Sigma Xi, the New York Academy of Science, the American Meteorological Society, and is Secretary of the Joint Commission on Radio Meteorology of the International Council of Scientific Unions.

Robert C. Fletcher (S'49) was born in New York, N. Y., on May 27, 1921. He received the B.S. degree in physics from the Massachusetts Institute of Technology in 1943. During the next three years he was engaged in electronic research at the MIT Radiation Laboratory, principally on magnetron oscillators. He then attended the graduate school in physics at MIT, having been awarded a National Research Council Predoctoral Fellowship.

R. C. FLETCHER

In June, 1949, he was awarded the Ph.D. degree. Since then he has been doing research in the electron dynamics group at the Bell Telephone Laboratories, Murray Hill, N. J.

❖

Loren F. Jones (S'26–A'26–M'38–SM'43) was born in St. Louis, Mo., in 1905. He received the B.S. degree from Washington University in 1926. After working on high-power transmitter development for General Electric for two years, he attended the Graduate School of Business Administration, at Stanford University, in 1928 and 1929, and then returned to General Electric.

L. F. JONES

In 1930, he joined the transmitter engineering department of the Radio Corporation of America in Camden, N. J., where he had charge of the development and design of various types of transmitters, co-ordinated the design of the WLW 500-kw transmitter, codirected the installation of the first television equipment atop the Empire State Building, and was technical representative of RCA in several European countries.

During the war years, he was a member of Division 13 (communications) and Division 14 (radar) of the Office of Scientific Research and Development, and was chairman of the Direction-Finder Committee. He was awarded the Presidential Certificate of Merit in 1948.

Mr. Jones is presently responsible at RCA for co-ordinating its research and development conducted for the government, and for new-product planning in certain fields.

He is a member of Sigma Xi, the American Society of Naval Engineers, and the Institute of Navigation. He is also an Associate Fellow of the Institute of the Aeronautical Sciences.

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H. J. Schrader (A'31–SM'38) was born in Schuyler, Neb., on May 2, 1900. He received the B.S. degree at the University of Nebraska in 1923. Mr. Schrader was associated with General Electric Company until 1930, working in the high-frequency section of the general engineering laboratory on the development of radio frequencies for measuring equipment. From 1930 to 1944, he was associated with the Radio Corporation of America in the capacity of supervisor of design and development of factory test equipment, and the design and development of test equipment for commercial sale.

H. J. SCHRADER

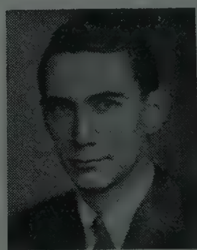
In 1944, Mr. Schrader was assigned to the Naval Research Laboratory's Combined Research groups, as supervisor of development and design of IFF test equipment. In 1946, he returned to RCA as group supervisor in the advanced development section of the engineering products department.

J. N. Marshall (M'46) was born in Newcastle, England, on June 22, 1916. He received the B.A. degree in mathematics and physics in 1939 from Cambridge University. Mr. Marshall joined the Telecommunications Research Establishment (R.A.F. radar) in 1940, and worked on decimeter radars and receivers. In 1943, he went with a British team to the Naval Research Laboratory, in Washington, D. C., and, in 1946, he joined the advanced development group of RCA Victor where he is now a unit supervisor. He served on special committees 31 and 41 of the Radio Technical Commission for Aeronautics.

J. N. MARSHALL

❖

Claude E. Shannon (M'48–SM'49–F'50) was born in Petoskey, Mich., on April 30, 1916. He received the B.S. degree in electrical engineering from the University of Michigan in 1936, and the degrees of S.M. in electrical engineering and Ph.D. in mathematics from the Massachusetts Institute of Technology in 1940. He was a National Research Fellow in 1941 and, since then, has been with Bell Telephone Laboratories as a research mathematician, working in the fields of communication theory, switching, and computing machines.



C. E. SHANNON

Dr. Shannon is a member of Sigma Xi and Phi Kappa Phi. He was awarded the Alfred Nobel Prize by the American Institute of Electrical Engineers in 1940 and the Morris Liebmann Award by The Institute of Radio Engineers in 1949.

Correspondence

Demonstration of Bunching Effects in a Klystron*

The velocity modulation or phase-focusing of an electron beam, in which the fluctuating transit times in the drift space cause the faster electrons to overtake the slower ones thus forming the bunches in a klystron, ordinarily is illustrated by the Applegate diagram.[1,2] This shows the alternating components of the electron density in the form of the converging and crossing trajectories.

As is well known, the bunching effect of an alternating control field depends on the distance along the drift space as well as on the momentary time and, therefore, repeats with each period. Consequently, the three-dimensional modification of the Applegate diagram portrayed in Fig. 1 is more il-

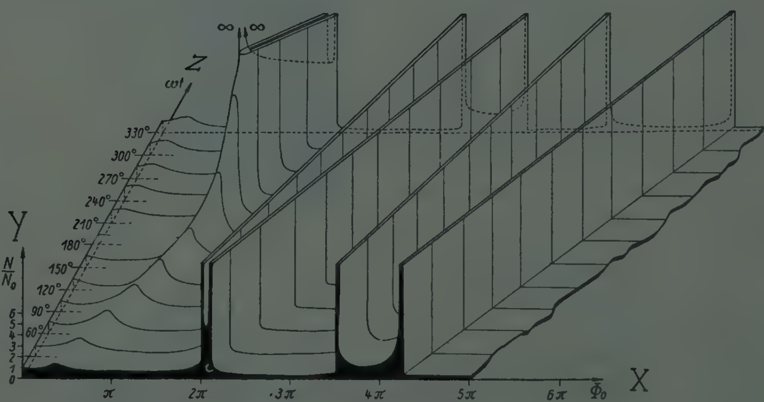


Fig. 1—Three-dimensional diagram of electron bunching.

* Received by the Institute January 9, 1950.

[1] D. R. Hamilton, J. K. Knipp, and J. B. H. Kuper, "Klystrons and Microwave Triodes," M.I.T. Radar Series, vol. 7, 1948.

[2] A. E. Harrison, "Klystron Tubes," New York, N. Y., 1947, including additional Bibliography.

lustrative. It differs from Kompfner's version[3] in that the X axis contains the distance along the drift space in terms of transit time angles, whereas the Z axis represents one period of the bunching field. The peaks and corners are computed under the ideal assumption of pure bunching, but actually they are leveled out and rounded off by debunching.

The periodic repeating of the bunching diagram suggests the third modification illustrated in Fig. 2. The former flat peak

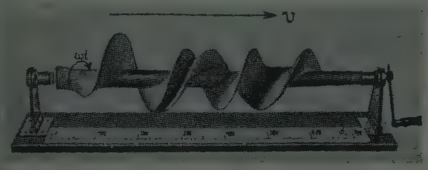


Fig. 2—"Living" model of electron bunching.

diagram is wound around the horizontal X axis, thus forming a peculiar type of helix similar to the screw feed of a meat grinder. When the model is rotated manually by means of the crank handle, the periodic formation and traveling of the electron bunches along the drift space become evident. Particularly the optimum transit time angle, assuring maximum efficiency of the fundamental component, and the following splitting up into two peaks which become more separated the more the bunching peaks travel, thereby producing increasing harmonics, can be seen very clearly. For demonstration purposes, the shadow of the model may be projected by parallel light onto a big screen so that the "life-like" bunching effect can be perceived by a larger audience. This procedure is very much simpler than the demonstration of the ballistic models[4] which serve more the purpose of studying the actual state of operation and the energy conversion in a klystron. The subsequent bunching effects in a cascade klystron may be demonstrated in a similar manner.

Hans E. Hollmann
105 N. "G" St.
Oxnard, Calif.

[3] R. Kompfner, "Velocity modulation—results of further considerations," *Wireless Eng.*, vol. 17, p. 478; November, 1940.

[4] H. E. Hollmann, "Theoretical and experimental investigations of electron motions in alternating fields with the aid of ballistic models," Proc., I.R.E., vol. 28, p. 282; June, 1940.

A Note on the Synthesis of Electric Networks According to Prescribed Transient Response*

In recent months we have seen the beginning of serious work in the solution of the problem indicated in the above title. In addition to my own,[1] there is that of Mulligan[4] and the two by Aigrain and Williams.[2,3]

* Received by the Institute, November 7, 1949.

[1] M. Nadler, "The synthesis of electric networks according to prescribed transient conditions," Proc. I.R.E., vol. 37, p. 627; June, 1949.

[2] P. R. Aigrain and E. M. Williams, "Design of optimum transient response amplifiers," Proc. I.R.E., vol. 37, p. 873; August, 1949.

[3] P. R. Aigrain and E. M. Williams, "Synthesis of n-reactance networks for desired transient response," *Jour. Appl. Phys.*, vol. 20, p. 597; June, 1949.

[4] J. H. Mulligan, Jr., "The effect of pole and zero locations on the transient response of linear dynamic systems," Proc. I.R.E., vol. 37, p. 516; May, 1949.

The last paper[3] I regard as a particularly elegant solution of the problem I so heavily treated. Perhaps the elegance is due to the French touch.

However, both Aigrain-Williams and myself had difficulties in finding proper functions to employ with our respective solutions. The former speak of "the difficulty of completing solutions, . . . of use primarily as a check on circuit designs derived by other means." In my own case, it was with great difficulty that I found a function which permitted an input shunt capacitance, and still could be treated by the chosen method.

Since the publication of these papers, I have found some conditions restricting the desired output function (of time, of course) if the network response found is to correspond to a practical vacuum-tube network; further, from these considerations, a hint for research in video amplifier feedback systems; and finally, a comprehensive statement of the mathematical problem involved in the *choice* of output functions.

Minimum Rise Time

Consider Fig. 1. $H(t)$ is the unit step (Heaviside) function. The (two-pole) load

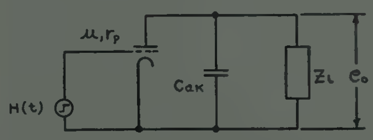


Fig. 1

consists of C_{ak} in parallel with Z_L. It is required to calculate τ, the minimum rise time attainable for any configuration of Z_L.

If the total charge delivered by the tube were available on the capacitor C_{ak}, then the output voltage would be

$$e_0 = \mu H(t)(1 - \epsilon^{-t/r_pC_{ak}}). \qquad (1)$$

But after the transient has ceased we want

$$e_0' = \frac{\mu H(t) R_L}{R_L + r_p} \cdot [R_L = \mathcal{R}(Z_L)]. \qquad (2)$$

The minimum t for which (2) is satisfied is found, from (1)

$$\tau = r_p C_{ak} \ln \frac{r_p + R_L}{r_p}. \qquad (3)$$

For the case of a pentode, where $r_p \gg R_L$,

$$\tau = R_L C_{ak}. \qquad (4)$$

From (3) it can be seen that the use of feedback to reduce r_p, in connection perhaps with triode amplifiers, would give significant reduction of τ. Of course, the feedback network itself will be a problem in itself, and I have not yet worked through the implications of this.

A similar reasoning will lead to the conclusion that the maximum value of the time derivative of e_0/e_0'

$$\frac{d}{dt}\frac{e_0}{e_0'} = \frac{r_p + R_L}{R_L r_p C_{ak}} \qquad (5)$$

$$\lim_{r_p \to \infty} \frac{d}{dt}\frac{e_0}{e_0'} = \frac{1}{R_L C_{ak}}. \qquad (6)$$

These two restrictions, on minimum rise time and on maximum rate of rise, must clearly be included in the expression of the required transient output, in order for that output to be realizable from the network as restricted by the need for C_{ak} to be the first shunt member.

Minimum Rise Time and Maximum Bandwidth

It has been shown that the maximum frequency to which an impedance terminated in a shunt capacitance C may have constant absolute value $|Z| = R$, is $f_c = 1/4RC$.

The minimum rise time and the maximum bandwidth attainable, with a given capacitor, are thus related in that the minimum rise time occupies a quarter period of the cutoff frequency. By analogy, it is expected that the minimum rise time for four terminal networks will be

$$\tau_4 = R_L\sqrt{C_iC_0} \qquad (7)$$

for the same output voltage as in the two-pole case.

Mathematical Form of $g(p)$ and $f(t)$

In the case of two-pole admittances for video amplifiers, $g(p)$ must be of the form

$$g(p) = kp + g'(p) \qquad (8)$$

where $k \leq 1/C_{ak}$. Other restrictions may be added, such as poles or zeroes at prescribed frequency bands. This is the case with United States intermediate-frequency amplifiers for television, where one sideband and the sound channel must be rejected.

The author has not yet been able to specify $f(t)$ so as to include all required conditions, and still yield a suitable $g(p)$. However, he has been able to catalog the conditions on $f(t)$ and $g(p)$ in the hope that others with greater mathematical ability than he may resolve the problem.

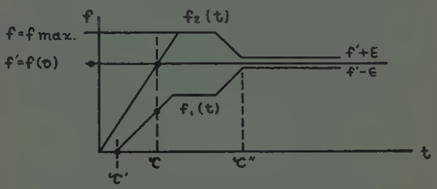


Fig. 2

Given $\tau' \equiv$ maximum delay; $\tau \equiv$ minimum rise time; $\tau'' \equiv$ maximum duration of transient; $f_{\max} \equiv$ maximum overshot,

$$f_1(t) \leq f(t) \leq f_2(t);\ f_1(0) = f(0) = f_2(0) = 0$$

$$1 - \epsilon \leq f_1(t) \leq f_2(t) \leq 1 + \epsilon \quad t \geq \tau''$$

$$\left|\frac{d}{dt} f(t)\right| \leq \frac{d}{dt} f_2(0)$$

where f_1 and f_2 are arbitrary functions. Now[1]

$$g(p) = \rho \int_0^\infty \epsilon^{-pt} f(t) dt \qquad (9)$$

where

$$f(t) = \int_{-i\infty}^{i\infty} \epsilon^{pt} \frac{g(p)}{p} dp, \qquad (10)$$

$g(p)$ satisfying the well-known conditions for a passive (physically realizable) network.

How do we write $f(t)$ such that it complies with the above restrictions, while yielding a $g(p)$ with the required poles and zeroes, corresponding to a passive network and which may be approximated by a convergent or asymptotically convergent rational function, or which may be easily realized by the Aigrain-Williams method?[3]

Morton Nadler
Tesla, Prague
Czechoslovakia

Institute News and Radio Notes

AUSTRALIAN IRE MEMBERS

Background, left to right: J. L. Pawsey, D. G. Wyles, R. C. Allsop, N. S. Gilmour, M. H. Stevenson, A. S. McDonald (standing), L. A. Hooke, H. B. Wood, G. H. Munro. Foreground, left to right: R. Edwards, Felix Gutman, N. T. Wedgner, K. S. Brown, I. C. Hansen. Immediate foreground: L. S. Hall.

AUSTRALIAN IRE MEMBERS ORGANIZE FIRST MEETING

(In presenting this item to the readers of the PROCEEDINGS OF THE I.R.E., pleasure and gratification may suitably be experienced at the friendliness, mutuality of interest, and close co-operation which exist between the Institution of Radio Engineers, Australia, The Institute of Radio Engineers, and the Australian membership of the IRE.—*The Editor.*)

International activities of the Institute were furthered by the first organized meeting of IRE members in Australia on December 19, 1949, at Sidney. Reflecting the close link between the IRE and the Australian Institution of Radio Engineers, H. B. Wood, Vice-President, and other members of the Australian Institution were guests. A. S. McDonald (M'23–F'41), Vice-President of IRE for 1949, addressed the gathering arranged by Murray H. Stevenson (A'39–SM'48).

Mr. McDonald spoke of the circumstances of the inception of the IRE through the active part taken by Dr. A. N. Goldsmith and others. From its origin with less than 50 members in 1912, the IRE has grown to an organization of more than 23,000 members in all countries of the world at the end of 1948. Despite the smallness of Australia's population there are 93 Australian IRE members, a total membership which is surpassed by only five other countries.

He pointed out that Australian members derive the greatest membership benefit from the PROCEEDINGS OF THE I.R.E., and that Australia has produced many finds conceived from the mine of information offered by PROCEEDINGS, and has in its own way contributed to the advancement of the electronic art.

IRE WEST COAST CONVENTION WILL BE HELD IN SEPTEMBER

Advances in civilian and military electronic and radio services in the West will be highlighted at the IRE West Coast Convention to be held September 13, 14, and 15, at the Municipal Auditorium, Long Beach, Calif.

The convention will feature a technical program combined with the Sixth Annual Exhibit of the West Coast Electronic Manufacturers Association.

NEW ENGLAND RADIO ENGINEERS WILL MEET APRIL 15 IN BOSTON

An outstanding program of technical papers will be offered to radio engineers attending the 1950 New England Radio Engineering Meeting to be held at the Somerset Hotel, in Boston, on Saturday, April 15. Sponsored by the North Atlantic Region of the IRE, the theme of the meeting is "Progress Through Research."

In addition to a morning and afternoon technical program, those attending the session will have opportunity to visit the television facilities of WBZ and to inspect the toll dialing equipment of the New England Telephone and Telegraph Company. Further information may be obtained from W. M. Broadhead, General Chairman, 131 Clarendon Street, Boston, Mass.

AIEE NOMINATES NEW OFFICERS

Titus G. Le Clair, assistant chief electrical engineer of the Commonwealth Edison Company, Chicago, Ill., was nominated to succeed James A. Fairman of New York as President of the American Institute of Electrical Engineers, at the Winter General Meeting held at the Hotel Statler, New York, N. Y., on January 31–February 3.

TECHNICAL COMMITTEE NOTES

The Standards Committee held a meeting on February 9 under the Chairmanship of John G. Brainerd. Ralph Batcher, Chairman of the Annual Review Committee, reported that on February 2, he attended an ASA Committee meeting on symbols for servomechanisms and feedback control system. This Committee is preparing definitions and will welcome IRE representation. ASA will be advised of IRE's interest in the work and its desire to have representation. **The Symbols Committee** has established a subcommittee to review abbreviations for use in text material. A similar group formed by ASA Sectional Committee Z-10 will be represented on the IRE Subcommittee. Chairman Brainerd announced **that a Committee on Electronic Instrumentation is** being set up in ASA at the request of IRE. Upon formalization, IRE will nominate a chairman. Axel G. Jensen will attend the next meeting of the National Research Council in connection with the preparation of the **Glossary of Nuclear Terms.** Mr. Jensen, Chairman of the Definitions Co-ordinating Subcommittee, reported on the several activities of this working group. M. Baldwin, Chairman of the Television Co-ordinating Subcommittee, reported on the activities of his group. A subcommittee was formed under the Chairmanship of Wayne Mason, to study IRE participation in the formulation of international standards. . . . **The Electron Tubes and Solid-State Devices Committee** met on January 12 under the Chairmanship of L. S. Nergaard. The Standard on **Definitions and Methods of Testing for Traveling-Wave Tubes, Magnetrons and Klystrons** will be completed this year. This committee will appoint a representative to serve on the Committee on Measurements and Instrumentation. The Electron Tubes and Solid-States Devices Committee will hold its 1950 Electron Devices Conference at the University of Michigan in June. John E. Gorham has been named Chairman of the 1950 Electron Devices Conference, details of which will be announced when the schedule is completed. . . . **The Wave Propagation Committee** held a meeting on January 25, under the Chairmanship of C. R. Burrows. All subcommittees of the Wave Propagation Committee held individual meetings on January 25, prior to the main committee meeting. H. O. Peterson, Chairman of the Subcommittee on Standards and Practices, reported that his group is in the process of rewriting new standards. Mr. Peterson stressed the need for new terminology. A report on the activities of the Subcommittee on Theory and Application of Tropospheric Propagation was given by Chairman Booker. This working group is planning a preparation of a bibliography. The first meeting of the Subcommittee on Theory and Application of Ionospheric Propagation, under the Chairmanship of A. H. Waynick,

was held on January 25. Dr. Sinclair reported on the activities of his subcommittee, Definitions and Publications, which also held its first meeting on January 25. Chairman H. W. Wells of the Subcommittee on Annual Review reported that the annual review material had been submitted for 1949. T. J. Carroll of the Wave Propagation Committee has recently been made Chairman of a Subcommittee on Tropsopheric Propagation in the CCIR. . . . **The Committee on Measurements and Instrumentation** held a meeting on January 20, under the Chairmanship of Professor Ernst Weber. Liaison between the various subcommittees of this committee and the other technical committees was discussed. Dr. Weber reminded committee members that they have been invited to attend meetings of all other technical committees whose work is related. Mr. Gaffney has been appointed Vice-Chairman of the Committee on Measurements and Instrumentation. W. B. George has accepted the Chairmanship of Subcommittee 25.1. Reports were made by chairmen present on their subcommittees. In the absence of Dr. George, Mr. Dalke submitted the report of Subcommittee 25.2. Mr. Fred A. Muller, Director of the Dielectric Laboratory of the Telephone Communications Laboratories, has agreed to participate in the work of this subcommittee. He is in charge of preparing standards for the ASTM on measurements above 100 Mc. Mr. Muller's service provides excellent coordination between IRE and ASTM. The Chairman of this subcommittee through his contacts at the National Bureau of Standards will also function as liaison with ASTM activities in Dielectric Measurements. Mr. Christaldi, Chairman of Subcommittee 25.10, attended a meeting on December 19, of the AIEE Joint Subcommittee on Electronic Instrumentation. An AIEE task group on Cathode-Ray Instruments is working on a project comparable to one phase of the work of the IRE Subcommittee on Oscillography. The work of the two groups will be co-ordinated by utilizing common personnel. The scope of this subcommittee will encompass activities of the present AIEE Task Group which is concerning itself with establishing definitions of terms, and a proposed standard form for specifications for cathode-ray instruments. It is expected that the IRE subcommittee will go further and co-ordinate techniques of oscillographic measurements in conjunction with the activities of other committees. Mr. Steen, Chairman of Subcommittee 25.11, reported that his group will tie in its work with the Professional Group on Quality Control. Mr. Mayo-Wells reported excellent progress in the organization of his subcommittee 25.13. This group will review the Telemetering Glossary prepared by J. F. Brinster for the Research and Development Board. J. C. Reid reported plans to organize his subcommittee 25.14 in two segments: a governmental and military group in Washington area, and a dominating industrial group in the New York area. Dr. Weber reported on the Symposium on Improved Quality Electron Components to be held in Washington next May. The Proceedings of the Symposium will be published as a pamphlet. The program will include five half-day sessions on utilized methods, on quality elements, and on miniaturization. J. G. Reid, Jr., Chairman of Subcommittee 25.14, has been appointed to the key post of Technical Program Chairman of this Symposium. Chairman Weber also reported that a petition for a Professional Group on Electronic Instrumentation had been approved by the IRE Executive Committee. Ultimately this group will take over the IRE Sponsorship of the Symposium on Improved Quality Electronic Components. . . . **The Video Techniques Committee** held a meeting on January 26, under the Chairmanship of J. E. Keister. The Chairman reported that liaison members from the Society of Television Engineers had been appointed to each of the subcommittees. Mr. Daugherty reported that his subcommittee is reviewing definitions which will be forewarded to the Definitions Co-ordinating Subcommittee for consideration. A report was given on the activities of Subcommittee 23.3, Video Systems and Components-Methods of Measurements. The following Standards prepared by this subcommittee will be published in the May issue of PROCEEDINGS. "Measurements of Timing on Video Switching Systems; and "Methods of Measurements of Resolution in Television." The "Standards on Methods of Measurement of Television Signal Levels" prepared by Subcommittee 23.4 was approved and will also be published in the May issue of PROCEEDINGS. . . . **A Meeting of the Steering Committee of the IRE/AIEE/RMA/ Symposium** on Improved Quality Electronic Components held a meeting on January 23, under the Chairmanship of F. J. Given. This Symposium will be held in Washington, D. C., on May 9, 10 and 11. . . . The Planning Committee of the **Third Annual Joint Nuclear Science Symposium** held a meeting on February 2. The Nucleonics Symposium will be held in New York City on October 23, 24, and 25. . . . The **Joint Technical Advisory Committee** held its meeting on January 13, at the Hotel Statler, Washington, D. C., prior to an informal conference with the Federal Communications Commission.

MIT Offers Fellowships in Electronic Research, Study

A number of graduate and advanced research fellowships are offered by the Massachusetts Institute of Technology for study and research in the field of electronics. Known as Industrial Fellowships in Electronics, they are sponsored jointly by a group of industrial organizations concerned with the advancement of electronics and its applications.

Applicants for Graduate Student Fellowships must satisfy the requirements for admission to the Graduate School on recommendation of the department of physics or the department of electrical engineering. Recipients will pursue programs of study and research leading towards advanced academic degrees in physics or electrical engineering.

There will be awarded a few Advanced Research Fellowships to candidates possessing the Ph.D. degree or its equivalent who, without enrolling as graduate students, wish to pursue advanced studies and research in the field of electronics at MIT.

Applicants should communicate with the Director, Research Laboratory of Electronics, at least four months prior to the intended date of entrance.

Johnson and Miller Appoint Censorship Problem Committee

A joint committee of the radio broadcasting and motion picture industries, charged with the task of co-operating against all forms of censorship and in other fields of common interest, has been appointed by Eric Johnson, president of the Motion Picture Association, and Justin Miller, president of the National Association of Broadcasters.

Appointment of the committee was followed by the unanimous adoption, by the boards of the two Associations, of a statement of principles and of opposition to all forms of censorship directed against freedom of expression.

Calendar of COMING EVENTS

American Society of Tool Engineers Meeting, Philadelphia, Pa., April 10–14

New England Radio Engineering Meeting, sponsored by North Atlantic Region of IRE, Boston, Mass., April 15

NAB Annual Engineering Conference, Chicago, Ill., April 12–15

IRE/URSI Meeting, Commissions 1, 4, 6, 7, Washington, D. C., April 17–19

Fourth Annual Spring Technical Conference, Cincinnati Section, IRE, April 29, Cincinnati, Ohio

1950 IRE Technical Conference, Dayton, Ohio, May 3–5

Conference on Improved Quality Electronic Components, sponsored by IRE, AIEE, RMA, Washington, D. C., May 9, 10 and 11

Armed Forces Communications Association 1950 Annual Meeting, Photographic Center, Astoria, L. I., N. Y., and New York City, May 12; Signal Corps Center, Fort Monmouth, N. J., May 13

IRE West Coast Convention of 1950, Municipal Auditorium, Long Beach, Calif., Sept. 13–15

Radio Fall Meeting, Syracuse, N. Y., October 30, 31, November 1

Bureau of Standards Revises WWV and WWVH Services

A new series of technical radio broadcast services over radio station WWV, Beltsville, Md., and WWVH, Maui, Territory of Hawaii, has been inaugurated by the National Bureau of Standards. These services will not differ greatly from those given in the past.

The revised services from WWV include standard radio frequencies of 2.5, 5, 10, 15, 20, 25, 30, and 35 megacycles; time announcements at 5-minute intervals by voice and International Morse Code; standard time intervals of 1 second, and 1, 4, and 5 minutes; standard audio frequencies of 440 cycles (the standard musical pitch A above middle C) and 600 cycles; and radio propagation disturbance warnings by International Morse code consisting of the letters W, U, or N, indicating warning, unstable conditions, or normal, respectively.

The audio frequencies are interrupted at precisely one minute before the hour and are resumed precisely on the hour and each five minutes thereafter. Code announcements are in Universal Time using the 24-hour system beginning with 0000 at midnight; voice announcements are in Eastern Standard Time. The audio frequencies are transmitted alternately: the 600-cycle tone starts precisely on the hour and every 10 minutes thereafter, continuing for 4 minutes; the 440-cycle tone starts precisely five minutes after the hour and every 10 minutes thereafter, continuing for 4 minutes. Each carrier frequency is modulated by a seconds pulse which is heard as a faint tick; the pulse at the beginning of the last second of each minute is omitted.

Radio station WWVH, recently established in Hawaii by the National Bureau of Standards, broadcasts on an experimental basis on 5, 10, and 15 megacycles. The program of broadcasts on the three frequencies is essentially the same as that of station WWV. Reception reports indicate that WWVH is received at many locations not served by WWV, thus extending the area served by standard frequencies and time signals. Time announcements in Universal Time are given from WWVH every five minutes by International Morse Code only.

Further information on the technical radio broadcast services may be obtained on request from the National Bureau of Standards, Washington 25, D. C. Reports on reception are welcomed; forms on which to submit such reports may also be obtained on request.

Treasury Refuses To Postpone Excise Tax For Loudspeakers

Following formal refusal, at least at the present, by the Internal Revenue Bureau to suspend its ruling of October 26 taxing loudspeakers, with or without transformers, arrangements have been made for renewal of the postponement request at a conference with Treasury officials by representatives of the RMA Speaker Section and Excise Tax Committee. Although the speaker tax ruling is continued in effect on the ground that not a sufficient showing has yet been made for its postponement, Chairman Matt Little of the Speaker Section and Vice-Chairman A. M. Freeman of the Excise Tax Committee have arranged for an early conference with the Treasury officials to present additional and more detailed facts in support of the RMA request for postponement.

Eastman Kodak Company Plans Color Television Symposium

Owing to current interest in the subject of color television, a special symposium on color and color photography as applied to television may be presented by the Eastman Kodak Company at Rochester, N. Y. in late May, provided sufficient registration is obtained.

Designed for engineers active in color television, the symposium would aim the subject of color and color photography directly at the color television field. The tentatively scheduled symposium would consist of illustrated talks and demonstrations followed by questions and discussion periods.

The symposium will be held if at least 25 individuals indicate that they would attend. Interested persons should send a tentative registration to: Eastman Kodak Company, East Coast Division, Motion Picture Film Department, 342 Madison Avenue, Suite 626, New York 17, N. Y. Each registrant would be notified by the middle of May as to whether the symposium would be conducted the latter part of May. If the symposium were to be conducted, full details would be sent at that time, including information regarding hotel reservations in Rochester.

The symposium would be an adaptation of a series of meetings currently being held for representatives of the motion picture industry. The following is a list of subjects, covered by the current meetings, which would be somewhat altered so as to apply directly to color television: Fundamentals of Color and Color Photography, Light Sources and Filters, the Perception in Identification of Color, Characteristics of Color Materials, Color Processes, the Problem of Duplication, Negative-Positive Color Processes, Color Sensitometry, Printers and Color Balancing, and Psychological Aspects of Color Photography.

NAB Seeks Government Action On Broadcasting Allocations

The National Association of Broadcasters' Board of Directors has adopted a resolution urging on the U. S. Congress, State Department, and Federal Communications Commission "the vital necessity of a new treaty" on broadcasting channel allocations, pointing out that the Cuban Government has authorized radio operations which "severely damage the coverage" of American stations.

The resolution, adopted at the close of the Board's three-day meeting at NAB headquarters, called attention to "the serious degradation of program service to millions of listeners in the United States of America."

Sylvania Electric Products Absorbs Colonial Radio Co.

Sylvania Electric Products Inc. has announced the absorption of its wholly owned subsidiary, Colonial Radio Corporation, manufacturer of radio and television sets. Operations will be continued in Buffalo, N. Y., as the Coloniel Radio and Television Division, Sylvania Electric Products Inc.

E. E. Lewis, formerly president of Colonial, has been elected vice-president of Sylvania in charge of the Colonial Radio and Television Division. The personnel and policies will continue unchanged.

300,000,000-Volt Synchrotron Passes Its First Test at MIT

A 300,000,000-volt synchrotron, which will be used for research on atomic particles, has passed its first operating tests in the Laboratory for Nuclear Science and Engineering at the Massachusetts Institute of Technology. Announcement of the completion of the test of the synchrotron, which was started in 1946, was made by Professor Jerrold R. Zacharias, Director. Its construction was supported in part by the Office of Naval Research, and the machine was designed and built under the direction of Ivan A. Getting, professor of electrical engineering.

The Institute's Synchrotron is powerful enough to produce mesons artificially, and should produce enough of them so that their behavior can be studied carefully. It is believed that from such studies may come new information in the realm of nuclear physics. Eventually, understanding of the meson may disclose the true nature of the forces that bind together the particles of the atomic nucleus.

Wave Propagation Is Subject of Symposium at NYU in June

"The Theory of Electromagnetic Wave Propagation" is the subject of a Symposium to be held June 6–8 at New York University, Washington Square College, New York, N. Y., under the sponsorship of NYU's Mathematic Department and the Geophysical Research Directorate of the Air Force Cambridge Research Laboratories.

Among the speakers will be Professor H. G. Booker of Cornell University, Dr. H. Bremer of Philips Research Laboratories, Eindhoven, Holland, Professors K. O. Friedrichs and Bernard Haurwitz of New York University, Professor R. E. Langer of the University of Wisconsin, Professor Harold Levine of Harvard University, Dr. Wilhelm Magnus of California Institute of Technology, and Professor Nathan Marcuvitz of Brooklyn Polytechnic Institute.

The Symposium is sponsored for the purpose of providing an exchange of views of those engaged in research in electromagnetic theory, basic applications to propagation, diffraction, etc., and the associated mathematical techniques and theory.

NBS Publishes New Booklet On Spectrophotometric Data

Reliable spectrophotometric data can be obtained from a new booklet, "Spectrophotometry," recently issued by the National Bureau of Standards and made available from the U. S. Government Printing Office.

The techniques and data resulting from the Bureau's extensive experience in spectrophotometry are presented in this guide so users of spectrophotometer can better understand their instruments, calibrate and maintain them in the proper operating condition, and guard against the numerous errors common in such work.

Instruments and methods for use in the ultraviolet, visible, and near-infrared spectral region are considered, including the photographic, visual, as well as the photoelectric methods.

Industrial Engineering Notes[1]

Television News

With RMA set production reports adding up to 2,413,397 television receivers, total output for the entire industry, according to the best information available, is believed to have exceeded 2,800,000 TV sets compared with an estimated 975,000 units in 1948. Radio receiver production, while rising during the fourth quarter of the year, declined for the year, however, to about two-thirds of the 1948 output. RMA figures on both AM and FM receivers totalled 7,266,876 in 1949, with an estimated industry output of more than 10,000,000 sets. Total television receiver production in 1949 brought the accumulated estimate of television receivers manufactured since the war to just short of 4,000,000. . . . An ultramodern **television, radio, and recording system is being installed** at the White House, now being remodeled. The built-in system will be operated from a central master control, and will feature a large television screen in every room. Each screen will be tuned in merely by dialing a number. In addition to the installation of big screens in all rooms, a giant six-by-eight foot TV screen will be placed in the small movie theater which is located in the executive offices section of the White House. The system also includes similar services for AM and FM radio programs, Muzak, as well as equipment to use wire and tape recordings and phonograph records in every room. . . . Reflecting the giant strides made in the production of television receivers in 1949, **the value of TV picture tubes sold for new sets** was almost triple the corresponding 1948 sales figures, according to tube manufacturers' reports to the RMA Tube Division. The value of television-receiver type cathode-ray tubes sold in 1949 to equipment manufacturers rose 197 per cent to \$92,402,520, compared with \$31,158,194 in 1948, while in units the increase was 170 per cent or from 1,225,419 to 3,305,673 tubes. Indicating a sharp trend toward larger TV set screens, more than 43 per cent of the TV picture tubes sold to set manufacturers in 1949 were from 12 through 13.9 inches in size, as compared with six per cent in 1948. Tubes from nine through 11.9 inches accounted for 34 per cent and tubes over 14 inches accounted for 16 per cent of manufacturers' purchases. The remaining sales were of tubes smaller than 8.9 inches and projection tubes. . . . Complying with an FCC request issued the middle of December, **parties to the current color television inquiry, including RMA, have filed formal comments with the FCC** on general recommendations previously on record in the FCC hearings. The statements filed by RMA, RCA, Philco, and CBS were on a procedural requirement. The RMA statement noted that any statements filed prior to the FCC hearings by the Association should be viewed by the FCC in the light of RMA President R. C. Cosgrove's later testimony. This referred specifically to an RMA major recommendation that any color television system authorized by the FCC should be compatible. Philco pointed out it had not changed its views, and CBS noted that there was no change in its position as outlined in previous written statements on file with the FCC. RCA called attention to several technical advances which it has made in its system, including an automatic color phasing development which was tested during the January session.

[1] The data on which these NOTES are based were selected, by permission, from *Industry Reports*, issues of January 20, January 27, February 3, and February 10, published by the Radio Manufacturers Association, whose helpful attitude is gladly acknowledged.

Radio and Television News Abroad

Holland expects to have its first non-laboratory television this year with receivers being placed on the market, and a station erected at Het Gooi, according to information received by the U.S. Department of Commerce. Transmissions will be made with 625 picture lines and on an experimental basis for the first two years under the over-all responsibility of the Netherlands Broadcast Transmission Co. It is estimated there will be 30,000 television viewers after two experimental years and 225,000 after six years of operation, according to the reports. **Radio dealers in Bristol, England,** were experiencing a rapidly **increasing demand for television receivers** prior to the opening in mid-December of Britain's second television station at Birmingham, according to a report received by the U.S. Department of Commerce. If the demand is as good as many expect, manufacturers will be unable to supply sufficient models to meet requirements, the report said. The Bristol interest in television is said to have increased with the reception of test signals from the new station. Up until recently only 73 television licenses had been taken out in the Bristol area. . . . An **estimated 11,360 radio receivers are in use in Nicaragua,** of which about half were manufactured prior to 1939. Approximately 90 per cent of the radios in operation are table models. An estimated 95 per cent of the sets are equipped to receive medium-wave and short-wave broadcasts. **Approximately 12,000 radio receivers are in use in Indo China,** of which about 95 per cent are of French manufacture. The remainder are principally Dutch, according to a report received by the U.S. Department of Commerce. **Imports of radios into Iran from** March 21, 1949, to **March 20, 1949, totalled 18,191 sets** valued at 37,491,942 rials, of which 12,292 receivers valued at 22,371,368 rials were of U.S. manufacture. . . . There is a growing interest in television in Germany, and a station may be erected in Hamburg by the middle of this year, according to a report received by the U.S. Department of Commerce. TV development for the most part is dependent upon radio amateurs. There are an estimated 2,800,000 radio receivers in operation in Italy, and about 70 per cent are equipped for short-wave reception. About 55,000 sets are located in public places. . . . **Restrictions on New Zealand's imports of** radio receiving tubes from the United States during 1950 are expected to be even more severe than in 1949. An estimated 30,500 radio receiving tubes, most of them obsolescent types and not available from sterling areas, will be imported from the United States this year.

FCC Actions

The FCC has **denied the petition of Prismacolor Pictures, Inc.,** of Wilmette, Ill., seeking permission to participate **in the color television hearings.** The FCC ruled that the petition of the company did not make a prima facie showing that the proposed system of color photography could be adopted to color television. "On the contrary," the FCC said, "it appears from your petition and statement that at the present time your proposed color television system is predicated on the asserted success of your color photography; that there has been no research and development of the proposed color television system in the laboratory to determine fundamentals and to explore basic problems; and that no transmitting or receiving apparatus have been constructed by you which would be suitable for either laboratory or field testing." . . . **The FCC in accordance with its rules and engineering practices concerning FM broadcast stations,** this week **issued an up-to-date list of manufacturers,** of approved FM transmitters, frequency monitors, and modulation monitors. The list, containing the names of transmitting equipment manufacturers and apparatus classified by type and power, may be obtained from the Secretary of the Federal Communications Commission, Washington 25, D. C. . . . The FCC has authorized a Class 2 Experimental station to the S. S. Pike Co., Inc., New York City, to be used up to Nov. 1, 1950, **to demonstrate a new type of sky writing.** Flying in a straight formation approximately 350 feet apart, seven aircraft would release smoke dots to stream out and outline block letters. The center plane would carry an automatically keyed tone-modulated transmitter which would activate receivers controlling smoke apparatus on the other planes. . . .

Muzak Corp. has petitioned the FCC to hold a hearing on the nonbroadcast uses of FM signals and other activities of some FM licensees. Muzak, which provides a leased music service with telephone lines, now seeks FCC permission for installing supersonic signals and a special form of multiplexing in connection with FM broadcasting. The petition charges that some stations are violating existing FCC rules by utilizing supersonic signals for the elimination of commercial announcements on FM station broadcasts. Muzak asked that until the rules are amended, the FCC advise all FM licensees that the service which some of them are now performing by the use of supersonic signals and the sale of service directly or indirectly, either by the station itself or through agency relationships to multiple addresses, is contrary to the FCC rules. The FCC has granted the Department of Forests and Waters of the State of Pennsylvania construction permits for 62 fixed stations in the Forestry Conservation Radio Service to be used for determining water levels throughout the Susquehanna River basin in connection with flood forecasting. The proposed new system will consist of a control center at Harrisburg, 11 automatic relay points, and 50 reporting units. It will operate on nine frequencies in the 170-Mc range. . . . The FCC has reversed itself and granted the Zenith Radio Corp. special temporary authority for a period of 90 days to conduct experimental operations employing "Phonevision." Previously, over the dissent of Chairman Wayne Coy and Commissioner George Sterling, the FCC had ruled that a public hearing should be held before the experiments involving paid subscriptions could be conducted. This action was opposed in a subsequent Zenith petition for reconsideration. . . . The FCC has been offered the assistance of 50,000 experienced television experimenters, who have assembled black-and-white television receiving sets from knock-down kits in their homes, to help decide which system of color television will best serve the American public. The offer was made in a letter written by Emanuel Cohan, President of Transvision, Inc.

National Television System Group of RMA Will Assist Color Standards

The creation of a National Television System Committee to attain industry-wide agreement on technical developments needed for the expansion of television to all sections of the country, and for the establishment of basic standards which will bring color television to reality, was announced by the Radio Manufacturers' Association.

W. R. G. Baker, vice-president of the electronics department of General Electric Company, and Director of RMA's engineering department, will serve as chairman of the group. Donald G. Fink, editor of *Electronics*, and David B. Smith, vice-president in charge of engineering and research of Philco Corporation, are vice-chairmen.

The following organizations and individuals have been invited to participate: Philco Corporation, *Electronics*, McGraw-Hill, DuMont Laboratories, Crosley Division of AVCO, Zenith Radio Corp., The Institute of Radio Engineers, Columbia Broadcasting System, Television Broadcasters Association, Bell Laboratories, General Electric Co., National Association of Broadcasters, Color Television, Inc., Hazeltine Corporation, Admiral Corporation, Motorola Inc., Westinghouse Electric Co., John V. L. Hogan, Federal Communications Commission, and the Radio Corporation of America.

Dr. Baker has told Chairman Coy that "we shall be pleased to have the FCC participate in the work of NTSC to the extent you desire." He added that the FCC will be advised at all times as to the work of the NTSC and "as additional representation is appointed."

House Group to Include TV in Its Proposed FCC Bill Publi Hearingc

Testimony on the FCC activities in connection with television, including color, is being given at public hearings by a subcommittee of the House Interstate and Foreign Commerce Committee to consider several bills affecting the administration of radio communications, RMA has been informed.

Acting Chairman Sadowski (Dem. Mich.), who introduced a bill to amend the Communications Act and revise certain functions of the FCC, said that industry representatives will be invited to testify in connection with the television phases of the inquiry.

The bill as introduced proposes three major changes in the Communications Act which would: (1) create an independent five member Frequency Control Board to deal with the allocation and assignment of radio frequencies; (2) broaden the FCC administrative authority with respect to radio station licensees and holders of construction permits; and (3) make radio station licensees immune from criminal or civil actions for statements made in political broadcasts and would clarify Section 315 of the Communications Act relating to such broadcasts.

RMA Names Industry Representatives to Slate International TV Exhibits

The Radio Manufacturer's Association, in response to a request of the U.S. State Department, has designated industry representatives to assist the Government in arranging for an international demonstration of American television in this country between March 27 and April 7. The demonstration will also include exhibits of color television, according to an announcement by Donald S. Parris, of the Office of International Trade.

The demonstration will be conducted for a group of European technicians comprising Study Group 11 of the International Radio Consultative Committee, which met last July in Switzerland to consider international television standards.

The following nations are members of the Study Group: Austria, Belgium, Czechoslovakia, Denmark, France, Hungary, Italy, the Netherlands, Sweden, Switzerland, United Kingdom, Yugoslavia, and the United States. Following the television demonstrations in this country, the Study Group will visit Paris and Eindhoven for the French and Dutch demonstrations from April 20–25, and London for a British demonstration from April 27–May 4.

W. R. G. Baker, Director of the RMA engineering department, has made the following appointments: President, R. C. Cosgrove; Director, Larry F. Hardy, President of Radio and Television, Philco Corp., Philadelphia; Director, Allen B. Dumont, President of Allen B. DuMont Laboratories, Inc., Clifton, N. J.; Karl Phillippi, General Electric Co., New York, N. Y.; Director, J. B. Elliot, Vice-President, RCA Victor Division, Camden, N. J.; and V. S. Mameyeff, Chairman of the RMA Export Committee, of the Raytheon Manufacturing Co., New York, N. Y.

RMA also recommended the following industry representatives to serve on an Administrative Subcommittee to be named by the State Department: Max F. Balcom, chairman of the RMA Television Committee and Vice-President of Sylvania Electric Products Inc., Emporium, Pa.; President Cosgrove; Donald G. Fink, editor of *Electronics*, New York, N. Y.; Dr. DuMont and Mr. Philippi.

The Technical Subcommittee held its first meeting on Tuesday, January 31, at the headquarters of The Institute of Radio Engineers in New York, N. Y.

Radio Propagation Laboratory to Move to Boulder, Colorado, Site

Approval has been given for the development of a site at Boulder, Colo., for additional laboratory facilities for the National Bureau of Standards. The site will be used initially by the Bureau's Central Radio Propagation Laboratory. Laboratory facilities costing $4,500,000 will be erected, with construction expected to begin in the summer of 1951, NBS said. When the laboratory is completed, a research staff of 300 people will be employed, with most of them being transferred from the present staff in Washington. The Bureau's radio work is being carried on in three units: The ionospheric research laboratory, the system research laboratory, and the measurements standards laboratory.

Army to Test Television for Training Reserve Components

The Army is presenting a series of eight experimental television programs designed to test television as a training medium for its Reserve Components, according to an announcement by General Mark W. Clark, Chief of Army Field Forces, Fort Monroe, Va. Time for the test programs, which began on February 9, has been donated by the Columbia Broadcasting System. General Clark emphasized that these are test training programs, the results of which will be studied in determining the possibility of using television as a training medium.

IRE People

Samuel Lubkin (SM'46), formerly consultant to the National Bureau of Standards, will head a new company, The Electronic Computer Corporation of Brooklyn, N. Y., which has been formed to meet the demand for companies specializing in electronic digital computers.

Dr. Lubkin's work with the National Bureau of Standards was concerned with the mathematical, logical, and engineering phase of electronic digital computers. He is one of the leading authorities of this highly specialized subject. Before his association with the NBS, Dr. Lubkin was in charge of the digital computer group of the Reeves Instrument Corporation, on loan to the Moore School of the University of Pennsylvania as consultant in the design of their EDVAC; and engineer in charge of computing machines at the Ballistics Research Laboratories, Aberdeen Proving Ground. As president of the Electronic Computer Corporation, Dr. Lubkin will actively direct and supervise production of both general purpose and special purpose computers and associated components. The company also will engage in research and consultancy in the field.

Benedict K. V. French (A'24–M'30–SM-'43), has been appointed application engineer of the Electronic Parts Division of Allen B. DuMont Laboratories, Inc., at East Paterson, N. J. He will collaborate with engineers and production men of various TV set manufacturers in fitting DuMont components to their assemblies.

Mr. French began his radio career in 1923 with Federal Telegraph and Telephone Co. as development engineer. Later he was with American Bosch in its development of the first all-wave radio sets, auto radios, and personal type receivers; with RCA's License Division Laboratory; and later with Case Electric as chief engineer.

While associated with P. R. Mallory Co. in 1937–1946 he was instrumental in the development of the Mallory-Ware Inductuner, now incorporated in the DuMont Inputuner used in DuMont and other quality TV sets. He was responsible for the introduction of push-button station selection and wave-band switching.

During World War I he served on the joint Army-Navy Standardization Board, and late in 1944 he became supervisor of Mallory research for the development of the mercury-type dry battery extensively used in armed forces radio equipment.

Harold B. Rothrock (A'37–VA'39) has established an office in the Citizens Bank Building, Bedford, Ind., where he will continue the practice of consulting radio engineering.

Karl G. Jansky (A'28–M'34–SM'43–F'47), of the technical staff of Bell Telephone Laboratories, Inc., who as a radio engineer became world-famous for his discovery of radio waves emanating from interstellar space, died recently.

Born 44 years ago in Norman, Okla., he was a son of Cyril M. Jansky, now professor emeritus of electrical engineering at the University of Wisconsin. Mr. Jansky received the B.S. degree from that university in 1927 and the M.A. degree in 1936. He was a member of Phi Beta Kappa, honor society, and Phi Kappa Phi and Phi Sigma Phi fraternities.

Mr. Jansky was an expert on radio transmission and particularly on atmospherics and other forms of interference. He was also known for his studies of noise in amplifiers and receivers, and for the design of several types of wide-band amplifiers. His work was done at the Holmdel, N. J., installation of Bell Laboratories.

Recently he received an Army-Navy Certificate of Appreciation for his work on radio direction finders in the second World War. He was made a Fellow of the Institute for his "researches in the realm of cosmic and circuit noise affecting radio communication."

B. Ray Cummings (A'18–M'20–SM'43) of Fort Wayne, Ind., died recently. He was born on September 5, 1891, at Lancaster, Pa.

Mr. Cummings, who was graduated from Columbia University in 1917, was with the United States Navy. He was in charge of the design and production of spark transmitters and associated apparatus for vessels of the U.S. Navy and Emergency Fleet Corp. until June, 1919. Then he was placed in charge of the Transmitter Laboratory at the Navy Yard, Washington, D. C., where he was responsible for the test and design of radio transmitters for Naval vessels, including transmitter of arc, spark, and valve types.

Ralph Hackbusch (A'26–M'30–F'37), president and managing director of Stromberg-Carlson Co., Ltd., Canada, was elected president of the Canadian Radio Technical Planning Board at the fifth annual meeting of the group.

C. Paul Young (A'37–SM'46) has been appointed government sales manager of the Industrial Division of Philco Corporation. After two years as a development engineer in the communications field, Mr. Young joined Philco in July, 1933.

During the war he was given a leave of absence to serve in the Electronic Division, Bureau of Ships, Navy Department, where he was engaged in airborne radar design work. He returned to Philco in November, 1945, as a sales engineer to develop the company's research and engineering contract work.

Mr. Young received the B.S. and M.S. degrees in electrical engineering from the University of Pennsylvania.

In his new position he will be responsible for customer relations and contract negotiations for commercial products, microwave relays for television and communications, television studio equipment, Loran, and other communications equipment.

Vladimir K. Zworykin (M'30–F'48), director of electronic research, vice-president and technical consultant, RCA Laboratories Division, Princeton, N. J., has been inducted into Eta Kappa Nu Association, the national electrical engineering honor society. Mr. Zworykin was honored at the Recognition Award Dinner held in New York City recently.

James H. Ludwig (A'37–VA'39–SM'48), president and treasurer of the Control Engineering Corporation, Canton, Mass., died recently. Mr. Ludwig was born on February 4, 1914, in Illinois.

He was graduated from Albion High School, and received the A.B. degree from Albion College in 1935. Mr. Ludwig earned the M.S. degree in physics at the University of Michigan in 1936.

He was associated with Philco Radio and Television Corp. during 1936 until 1938, and then transferred to RCA Victor at Camden, N. J., where he took part in radio engineering on commercial and government equipments. From 1944 until 1948 he was affiliated with Raytheon Manufacturing Co., Waltham, Mass., as department manager of an engineering group of approximately 120 people concerned with the Navy contracts on guided missiles.

IRE People

Harold W. Schaefer (A'44) has been appointed a special assistant at the Philco Corporation. Mr. Schaefer has been active as a radio, electronics, and television engineer for the past 24 years. He will handle special duties in connection with research and engineering for the Philco Television and Radio Division.

Mr. Schaefer had been assistant manager of the Westinghouse Home Radio Division since 1944. He was also in charge of product development and director of research and engineering on radio and television receivers. He commenced his career in the industry with Grigsby-Grunow in 1926, and made several basic contributions to the design and production of radio sets. During the second World War, Mr. Schaefer served at the Applied Physics Laboratory of The Johns Hopkins University, where under OSRD he had charge of engineering production of the "VT" proximity fuze.

Mr. Schaefer attended the University of Chicago and Lewis Institute.

Commodore John V. Murphy (SM'47), USN, retired, of Arlington, Va., died recently, He was a native of Texas, where he was born on June 12, 1893.

A graduate of Brownwood High School, Texas, the deceased earned the B.S. degree from the United States Naval Academy in 1917. He received the M.S. degree in 1924 from Yale University.

Upon his retirement from the Navy, he was associated during 1946 and 1947 with the Collins Radio Company as executive sales manager. From 1943 until 1945 he was deputy director of Naval Communications with the U. S. Navy Department, and formerly had headed the Radio Engineering and Communication Engineering Graduate School of the U. S. Naval Academy.

Walter Weiss (A'41) has been elected vice-president of the Hickok Instrument Company of Cleveland, Ohio, whose electronic division he started. Mr. Weiss is a graduate of the University of Southern California.

Following his graduation, he taught aeronautical engineering at East Technical High School, and then became associated with the General Electric Co. Prior to his association with Hickok Instrument Company, he had formed the Weiss Development Co.

Mr. Weiss is a member of the American Institute of Electrical Engineers and of Beta Kappa Nu honorary fraternity.

Roger M. Wise (A'26–M'30–F'37), an authority on radio vacuum tubes, died recently at Temple University hospital. For the past year since his own firm, Roger M. Wise, Inc., was acquired by Philco Corp., Mr. Wise had served as a special consultant on vacuum tubes for Philco. He was a nationally recognized authority in his field, and was widely known in the radio and television industry with which he had been associated for almost thirty years.

During World War II, Mr. Wise was honored with the Presidential Citation of Merit for his engineering work on the radio-proximity fuze. The invention is believed to have civilian value in the production of pocket radios and improved hearing aids, and in radar installations on airplanes.

Born at Fort Wayne, Ind., he served as chief electrician in radio in the U. S. Navy from 1917 to 1918, and then attended the University of California.

He was chief engineer of the Remler Manufacturing Company and E. T. Cunningham of San Francisco and New York from 1922 to 1929. Then he was affiliated with Sylvania Electric Products Inc., and became successively chief engineer, director of engineering, and vice-president in charge of engineering, serving in the latter capacity until 1946.

He inaugurated a program for the development of a 6.3-volt tube for automobile radios, a 1.4-volt tube for portable radios, and the "lock in" group of tubes.

George O. Milne (M'43–SM'43), director of technical operations, American Broadcasting Company, Inc., died recently. A resident of Wood-Ridge, N. J., Mr. Milne had been in radio work since 1923.

As a boy Mr. Milne experimented with crystal radio sets and later studied at the Western Electric installation school. In 1923 he became a maintenance man for station WEAF, New York, N. Y. He was made control supervisor in 1927 and operations supervisor the following year. Mr. Milne became division engineer for the National Broadcasting Company in 1930, remaining there until 1942 when he joined the ABC.

Cyril E. Maitland (A'47), who had been director and proprietor of Maitland Electronic Company of Harrow, Middlesex, England, died recently. Born in England on August 9, 1906, Mr. Maitland was educated at Harrow County School and Northampton Engineering College. He received the B.S. degree from London University in 1927.

He became associated with Baird Television in 1936, in charge of research into uhf television relaying via concentric cables. In 1941 he was placed in charge of Research and Development Laboratory for the Mullard Radio Valve Co. on miniature components.

Prior to the establishment of Maitland Electronic Company, and his consultant work on production of experimental and prototype models for electronic applications, he was engaged in technical liaison with research laboratories and government departments of A. C. Cosser Ltd.

Gaylord E. Durham (A'44), studio field engineer of the American Broadcasting Company of Hollywood, Calif., died recently.

Formerly he had been associated with the U.S. Navy Radio and Sound Laboratory, Point Loma, Calif., as an associate engineer. From 1940 until 1943 he was chief engineer of KFSD, a station with which he had been associated since 1938. Previously he had been with Aztech Radio Tech at San Diego, Calif.

Mr. Durham was born on March 18, 1898, in Kansas.

Bernard Eichwald (S'41–A'42–M'46), chief engineer of B. Eichwald and Company, Inc., of New York, N. Y., has been elected vice-president of the company by the Board of Directors.

He began his career with the electrical engineering and contracting firm in 1940. During 1941 he was associated with Federal Telegraph and Telephone Co., working on radio transmitters for the U. S. Army Signal Corps and direction finders for the CAA

Mr. Eichwald, who was born May 7, 1921, in New York, N. Y., is a graduate of James Madison High School, Brooklyn, N. Y., and of Rensselaer Polytechnic Institute, Troy, N. Y., receiving a bachelor of science degree in electrical engineering in 1942.

Frederic P. Fischer (M'46–SM'49) has been appointed as professor and head of the department of electrical engineering of the University of Buffalo, effective February 1, 1950. Formerly, he was an associate professor of electrical engineering at the University of Connecticut.

Books

Theory of Oscillations, by A. A. Andronow and C. E. Chaikin

Published (1949) by Princeton University Press, Princeton, N. J. 336 pages+7-page index+10-page appendix+ix pages. 309 pages. 9×6. $6.00.

This book was published originally in Russia in 1937, and is appearing now as an edited translation made by a group at Princeton University. A portion of the book already has been available in the work of N. Minorsky, "Nonlinear Mechanics," first published as a wartime report.

In the book is presented the basic mathematics relating to the theory of nonlinear oscillatory systems. The treatment begins with a discussion of linear systems and the graphical representation of their performance as trajectories on the phase plane. Nonlinear systems, first conservative and then nonconservatives, are considered next, still using primarily the technique of the phase plane. In this way, the reader is given a real picture of what is happening in the physical system and is led smoothly from familiar phenomena to that which is new to him. Later chapters are concerned with analytical methods for attacking the nonlinear problems, including particularly such points as the stability of the system and the appearance of limit cycles in the trajectories of the phase plans.

Throughout the book a number of physical examples are given, originating as systems both mechanical and electrical in nature. The interested reader will discover treatments of such diverse items as the clok, the Prony brake, parallel generators, sinusoidal oscillators, relaxation oscillators, and feedback amplifiers. The engineer may find that he is familiar with the physical phenomena described, but has not been aware of all that actually is taking place. Many figures serve to illustrate the mathematics.

The book is recommended to all those who are interested in learning more about the basic analysis of nonlinear oscillating systems and the differential equations that describe them.

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TV Picture Projection and Enlargement, by Allan Lytel

Published (1949) by John F. Rider Publisher, Inc., 480 Canal St., New York 13, N. Y. 174 pages+3-page index+2-page bibliography+ix pages. 5⅜×8½. $3.30.

To the radio and television service man, Rider publications, of which this book is one, are known for their completeness and helpfulness. The present book deals with a subject never before associated with home radio: Optics. With the exception of the first two theoretical chapters on Properties of Light and Refraction and Lenses, the average TV service man will find it easy to follow the clear exposition of such subjects as: The Television Picture, Schmidt System, Refractive Projection, and the more speculative systems for theatre television, the Skiatron and Sypersonic Systems. For the student there is a list of review questions following each chapter.

Optical servicing notes are given for these commercial television projection sets: Philco, Scott, G. E. Co., RCA, both home models and TL586 large screen, Television Assembly Co., U. S. Television Mfg. Corp., and Spellman. The electrical circuits of the receivers are not discussed.

Less than 5 per cent of television sets are of the projection type, but if I were a service man contemplating adjustment of one of these and had the opportunity to read this book—it does not take long—I would approach the job with a feeling of superiority that comes from knowing fundamentals. But, frankly, I believe that I could service the optics of the set just as well if I had read only the manufacturer's service instructions.

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Description of a Relay Calculator, by the Staff of the Computation Laboratory

Published (1949) by the Harvard University Press, Cambridge, Mass. 264 pages+5½-page index+xvi pages+37-page appendix. 219 figures. 8×10½. $8.00.

The Harvard Computation Laboratory, under the direction of Professor H. H. Aiken, has designed and constructed three large-scale digital calculators. The first of these, Mark I, was described in Volume I of the Annuals of the Computation Laboratory. The book under review is Volume 24 in the series and describes the Mark II calculator, which is now in use at the Dahlgren Naval Proving Ground. The recently completed Mark III, largely an electronic rather than relay calculator, will be covered in a later volume.

The Mark II contains some 13,000 relays and is controlled by a routine from punched tape. The speed of elementary operations is as follows: addition, 0.2 sec.; multiplication, 0.7 sec.; division, 4.7 sec.; tape reading, 1.5 sec.; determination of elementary functions, 5–10 sec. Numbers are represented by the "floating-decimal" method, i.e. $\pm p \cdot 10^n$ with p given to ten significant figures and n ranging from -15 to $+15$. The machine is divided into two identical parts which can be used either independently for two problems or together for one.

After describing the general functional organization of the calculator, each of the components is treated in detail down to individual circuit diagrams. The relay circuits involved are often ingenious and exhibit nicely the amazing versatility of these elements. The final chapters deal with operation and problem preparation for the machine. Various general observations scattered through the text will be of interest, for example, the statement that number transfers, additions, and multiplications occur in the approximate ratio 3:2:1.

The book is well illustrated and the style clear and straightforward, if perhaps a trifle dry. Those interested in the design and operation of computers will find it a valuable reference volume, not only in connection with the Mark II calculator, but also with regard to general questions of programming, checking, and methods of implementation that arise with any computer.

Claude E. Shannon
Bell Telephone Laboratories, Inc.
Murray Hill, N. J.

Communication Circuits, by Lawrence A. Ware and Henry R. Reed, Third Edition

Published (1949) by John Wiley and Sons, Inc., 440 Fourth Ave., New York, N. Y., 396 pages+5-page index+x pages. 201 figures 6×9. $5.00.

This is a very good book "intended as first-course material for all students of communication engineering, regardless of the frequency range with which they will be concerned." The material is limited to lumped networks and transmission lines. No active circuits are included. For the field covered, the choice of material is good. Furthermore, the relationship of high-frequency to low-frequency concepts is well shown.

Starting with the fundamental concept of elements of inductance, capacitance, resistance, and conductance, the authors derive elementary network theory in a highly satisfactory fashion, showing the detailed algebraic steps but not stopping there. Appendices develop hyperbolic and Bessel functions as well as Maxwell's equations. It is encouraging to see the professors of at least some schools equalling the students' lack of fear of mathematics.

Lines with uniformly distributed parameters, filters, waveguides, and coaxial lines are developed in the body of the book. These last are developed by means of field theory. A sufficient use of Maxwell's equations is made to give the student some facility with them as a background for advanced work.

It seems trivial to note that the book is not a good reference book. All the adverse opinions I have heard are from those using the book as such. The authors have not completely eliminated some of the informalities complained of by Mr. Wilson in reviewing the Second Edition.

These are minor comments, however. In the main, the authors are to be congratulated on a job well done.

Knox McIlwain
Hazeltine Electronics Corp.
Little Neck, L. I. N. Y.

Books (continued)

The Motion Picture Theatre-Planning and Upkeep, Edited by Helen M. Stote

Published (1948) by Society of Motion Picture Engineers, Inc., 342 Madison Ave., New York 17, N. Y. 429 pages+158 figures. 9×6½. $5.00.

This book "offers the entire motion picture industry an opportunity to read or review all of the technical papers and the ensuing discussions as they took place at the Conference on Theater Design" held in New York, October 20–24, 1947.

The topics covered include an introduction on the advancement of motion picture theater design and the psychology of the theater; and sections on the physical construction of the theater, auditorium design, ventilating and air conditioning, acoustics, lighting, floor coverings, promotional display and television. Most of the papers in this collection are by recognized leaders in the field, and for that reason are worthy of careful study.

My chief objection to this book is the title. The reader is led by it into thinking that the book can be used as a guide to good theater design. The nature of the papers, however, is such as to cover only a portion of the design factors and to do this in a non-integrated way. My suggestion for a title to this book would be, "Symposium on the Motion Picture Theater—Planning—Upkeep." Such a title would signal from the start that the book is a collection of program papers.

In illustration of this, the section on Acoustic Design unfortunately gives an unbalanced picture. Three papers are contained, which by title would seem to cover the acoustical design factors for moving picture theaters. The first paper presents rules in regard to cubic foot volume in relation to number of seats, the reverberation time at 512 cycles as a function of room volume, and the ratio of reverberation time at any frequency to reverberation time at 512 cycles. Also, it treats briefly the problem of internal shaping. The second paper gives a useful listing of the various factors contributing to noise in the theater. The third paper briefly describes two main categories of acoustical material. Also, a new method for measuring absorption coefficients of materials and the effects of painting some materials is treated.

No mention is made of the controversy that has been going on in the SMPE in regard to the difference between the published optimum values of reverberation time and the reverberation time found in actual moving picture theaters in this country and in Europe. Also, there is no description of the selection and design of acoustical materials or resonators which will produce the optimum reverberation characteristics suggested in these papers. Furthermore, of the two examples shown of theater design, only one is a movie theater; the other one is used for orchestra and organ and necessarily is somewhat different from good motion picture theater design. In spite of these comments, the three papers contained much material of value and are well worth reading.

The other sections of the book make interesting reading for someone like myself who has not encountered the moving picture theater problem as a whole before. It seems very probable to me that my comments in regard to the section on acoustics are also applicable to other sections of the book.

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Reference Data for Radio Engineers, Third Edition

Published (1949) by Federal Telephone and Radio Corporation, an association of International Telephone and Telegraph Corporation, 67 Broad St., New York 4, N. Y. 640 pages+28-page index+345 figures. 8¾×5¼. $3.75.

The third edition of this popular handbook of general information on radio matters represents a notable increase in contents over previous editions. It is now three times the size of the first edition, and consists of a compilation of well-chosen design information in the way of physical, mathematical and electrical formulas, constants, charts, etc.

Earlier editions have been well received by engineers, even those in fields only remotely associated with electronic matters, and it is rapidly becoming the standard-reference book of the industry.

The new material includes many nomographic charts, graphs and diagrams, and an extensive compilation of the characteristics of most insulating materials at various frequencies. A substantial section on high-frequency tubes, of the traveling-wave, klystron, magnetron, cathode-ray, etc., types and on tube-circuit design methods for various applications is also a new addition. Among many other added features are: radar fundamentals, filter-network design, Laplace transforms, electroacoustics, servomechanism fundamentals, multivibrators and special oscillators.

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Fundamentals of Vacuum Tubes, by Austin V. Eastman

Published (1949) by McGraw-Hill Book Company, 330 West 42 St., New York 18, N. Y. 600 pages+4-page index+30-page appendices+xxi pages. 462 figures 9×6. $5.50.

This is the third edition of this well-known text, intended primarily for the use of senior electrical students in an engineering college, and consequently the background of experience gained by the author has been brought to bear in rearranging and clarifying the presentation. As in previous editions, the title is perhaps slightly misleading because the main emphasis appears, as probably it should in a text designed for general classroom use in electrical engineering courses, to be directed more particularly to the *uses* of vacuum tubes than to the physical properties of the tubes themselves. In this aspect, therefore, vacuum-tube circuits are dealt with in a wide variety of forms. For example, Part I, which is entitled "Basic Concepts," comprises some 160 pages whereas Part II, "Applications and Circuits," contains 437 pages. An interesting feature of the book is an appendix containing a list of definitions and graphic symbols.

Generally speaking, the presentation is clear and accurate. In a few cases the attempt to avoid some of the more complicated phases of the subjects discussed has led to the use of abbreviated statements that could be misleading, as, for example, the statement on page 559 concerning pulse modulation that, "As in frequency and phase modulation, however, the increased bandwidth is accompanied by a marked improvement in signal-to-noise ratio."

The author frankly states that, after consideration, the subject of special tubes and circuits for ultra-high-frequency uses has been omitted as demanding either a seriously curtailed treatment or an undesirably long book. On the horns of such a dilemma, the decision to omit the material entirely may be justified, although it would be interesting to see, in the event that a fourth edition were ever to appear, whether a way would not have been found to include the material.

As with most of the recently written college texts on vacuum tubes and their circuits, the reviewer has looked in vain for even a brief section entitled "Telephone Repeaters."

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Radio Operator's License Q&A Manual, by Milton Kaufman

Published (1950) by John F. Rider Publisher, Inc., 480 Canal Street, New York 13, N. Y. 608 pages. 5½×8½. $6.00.

Based on the latest Government Study Guide and supplementary FCC releases, this new volume lists the questions and answers to past FCC examinations, and presents a detailed discussion of answers for more complete understanding of technical questions. It is profusely illustrated. A feature of the book is the appendices (Small Vessel Direction Finders and Automatic Alarm), never before available in a book of this type.

Intended for both the student reader and the radio operator, the books covers the following chapter headings: Elements I, II, III, IV, V, VI, Amateur Radio Questions and Answers, Q&A for Classes A, B, and C Radio License, Rules Governing Amateur Radio, Appendix I, Part 13, Appendix II, Extracts from Radio Laws, Appendix III, Conventional Abbreviations, International Morse Code, Appendix IV, Small Vessel Direction Finders, Appendix V, Automatic Alarm—Complete Index.

Abstracts and References

Prepared by the National Physical Laboratory, Teddington, England, Published by Arrangement with the Department of Scientific and Industrial Research, England, and *Wireless Engineer*, London, England

NOTE: The Institute of Radio Engineers does not have available copies of the publications mentioned in these pages, nor does it have reprints of the articles abstracted. Correspondence regarding these articles and requests for their procurement should be addressed to the individual publications and not to the IRE.

The number in heavy type at the upper left of each Abstract is its Universal Decimal Classification number and is not to be confused with the Decimal Classification used by the United States National Bureau of Standards. The number in heavy type at the top right is the serial number of the Abstract. DC numbers marked with a dagger (†) must be regarded as provisional.

The Annual Index to these Abstracts and References, covering those published in the PROC. I.R.E. from February, 194,9 through January, 1950, may be obtained for 2s. 8d. postage included from the *Wireless Engineer*, Dorset House, Stamford St., London S. E., England. This index includes a list of the journals abstracted together with the addresses of their publishers.

ACOUSTICS AND AUDIO FREQUENCIES

016:534 521
References to Contemporary Papers on Acoustics—A. Taber Jones. (*Jour. Acous. Soc. Amer.*, vol. 21, pp. 639–646; November, 1949.) Continuation of 1 of February.

534.121.1 522
Vibration of a Metal Plate in a Sound Field—T. Vogel. (*Jour. Phys. Radium*, vol. 7, pp. 193–201; July, 1946.) The theory of acoustic transparency is discussed and an approximate expression is derived for the transparency of a plate for excitation frequencies considerably different from its fundamental resonance frequency. A method is described for the measurement of transparency. Results obtained for four Al plates, of thickness 1 mm and of sizes from 2 m×1 m to 33 cm×25 cm, confirm the theory given but are not in agreement with the theory of Davis (1933 Abstracts, p. 219), especially for the smaller plates.

534.21 523
General Expression for Huyghens' Principle for Attenuated Propagation of Longitudinal Waves—J. Brodin. (*Compt. Rend. Acad. Sci.* (Paris), vol. 229, pp. 989–991; November 14, 1949.) It is required to determine a surface distribution of sources on a closed surface S which produces the same wave outside S as a given distribution of sources inside S. If the medium is imperfectly transparent, the solution is not unique; the general solution involves a single-layer distribution and a double-layer distribution over S, one of these layers being arbitrary. Among these solutions, however, only one gives no wave inside S. See also 712 below.

534.213 524
The Acoustic Characteristics of Conical Pipes—M. Mokhtar and G. A. Messih. (*Proc. Phys. Soc.*, vol. 62, pp. 793–799; December 1, 1949.) Experimental investigation of slightly tapered pipes to determine end corrections and the variation of velocity and pressure along the pipe. The resonance frequencies are in fair agreement with the theoretical formula $kr=-\tan kl$ (r=throat radius, l=slant length, and $k=\omega/c$, where c is the velocity of sound). The nodes are not equidistant and pressure at the nodes is not zero. The end correction is given approximately by the empirical expression $0.6r+(0.6l-2100/n)\sin\theta$, where n is the resonance frequency and θ the semi-apical angle of the cone.

534.231:534.121.1 525
Pressure Distribution in the Acoustical Field Excited by a Vibrating Plate—J. Pachner. (*Jour. Acous. Soc. Amer.*, vol. 21, pp. 617–625; November, 1949.) The computed distribution is based on an exact expression for the form of the vibrations in the circular plate, and is valid at distances from the center of the plate greater than 10–20 times its radius. A short survey of the theory of forced vibrations is included.

534.321.7:621.396.615.11 526
Tone Source for Tuning Musical Instruments—E. L. Kent. (*Electronics*, vol. 22, pp. 164, 166; December, 1949.) A Hartley oscillator produces two alternative timbres for the notes A and B♭, the semitone relation being retained irrespective of the setting of a control for the frequency of A in the range 435–445 cps.

534.321.7.08 527
International Standard Musical Pitch—L. S. Lloyd. (*Jour. R. Soc. Arts*, vol. 98, pp. 74–85; December 16, 1949. Discussion, pp. 86–89.) A verbatim report of a paper read before the Society on November 16, 1949. The history of the adoption of standard pitch is traced from the French decree of 1858 to the British Standards publication B.S. 880/49 of July, 1949, which defines the international standard of concert pitch to be based on a frequency of 440 cps for the note A in the treble clef.

534.321.9 528
Measurements on the Absorption of Ultrasonics in Water—A. van Itterbeek and P. Slootmakers. (*Physica,'s Grav.*, vol. 15, pp. 897–905; October, 1949. In English.) A balance method was used, at a frequency of 1500 kc. If α is the absorption coefficient and ν the frequency, $\alpha/\nu^2=55\times10^{-17}$ sec^2 per cm at 22° C, which agrees well with the value obtained for frequencies over 10 Mc. Absorption in a NaCl solution was also measured as a function of concentration.

534.321.9 529
Scattering of an Underwater Ultrasonic Beam from Liquid Cylindrical Obstacles—P. Tamarkin. (*Jour. Acous. Soc. Amer.*, vol. 21, pp. 612–616; November, 1949.) Long summary of part of a thesis.

534.42+538.561 530
Production and Observation of High Frequencies due to Combination of Several Low Frequencies—Dolinski. (*See* 560.)

534.612.4 531
The Plane Wave Reciprocity Parameter and Its Application to the Calibration of Electroacoustic Transducers at Close Distances—B. D. Simmons and R. J. Urick. (*Jour. Acous. Soc. Amer.*, vol. 21, pp. 633–635; November, 1949.) "The reciprocity parameter for a plane wave sound field is shown to be equal to $2A/\rho c$, where A is the area of the plane piston source and ρc the characteristic acoustic resistance of the medium. It is shown experimentally that the sound field in front of a plane piston source is effectively plane over a distance approximately equal to A/λ, and that in such a region the plane wave parameter may be used to obtain a free-field calibration of the transducer by the reciprocity method."

534.78 532
Theory of Speech Masking by Reverberation—R. H. Bolt and A. D. MacDonald. (*Jour. Acous. Soc. Amer.*, vol. 21, pp. 577–580; November, 1949.) A general statistical theory, in which speech is regarded as a series of discrete pulses distributed over a 30-db range in sound-pressure level in a given frequency band.

534.843 533
Acoustics of Rooms—M. A. S. Ross. (*Nature* (London), vol. 164, pp. 1080–1081; December 24, 1949.) Summary of a course of 6 lectures by R. H. Bolt, which included reviews of accepted theory, recent progress, and problems requiring further investigation.

534.844.4 534
Problems of Sound in Large Halls with Strong Reverberation—T. S. Korn. (*HF* (Brussels), No. 4, pp. 103–108; 1949. In French, with English summary.) Reasons for reduced intelligibility in certain halls are discussed. The simplifications generally accepted for the acoustic study of halls do not apply when the reverberation time is large. Methods for reducing the reverberation effect are discussed and an 'apparent reverberation time' is introduced, in which account is taken of the duration of the exciting sound. The most effective procedure for reducing reverberation is to increase as far as possible the intensity of the direct wave relative to that of the reflected wave.

534.86:621.396.619.13:621.396.712 535
A Demonstration of Experimental F.M. Broadcast Transmitting and Receiving Equipment—W. W. Honnor. (*Proc. I.R.E.* (Australia), vol. 10, pp. 35–41; February, 1949.) 1948 Australian I.R.E. Convention paper. The equipment is described and an analysis of a listening test is given. The results indicate that FM broadcasting transmissions, if reproduced by high-quality receivers, will be more acceptable to the majority of listeners than the service provided by the existing AM medium-frequency system, if conventional superheterodyne receivers are used.

621.395.61/.62 536
A Low-*Q* Directional Magnetostrictive Electroacoustic Transducer—L. Camp and F. D. Wertz. (*Jour. Acous. Soc. Amer.*, vol. 21, p. 636; November, 1949.) Correction to 3022 of 1949.

621.395.61/.62 537
Theory of Passive Linear Electroacoustic Transducers with Fixed Velocity Distribution—L. L. Foldy. (*Jour. Acous. Soc. Amer.*, vol. 21, pp. 595–604; November, 1949.) In previous papers (3559 of 1945 and 1990 of 1947) a general theory of transducers was developed. The special case of a fixed velocity distribution is now analyzed in simpler mathematical terms but in greater detail. The impedances, transmitting and receiving responses, directional properties, and efficiency are considered, and the 'reciprocity' and 'available acoustic power' theorems are proved. Summary noted in 939 of 1949.

621.395.61 538
Sensitivity and Fidelity of Microphones—J. Henry. (*Radio Franç.*, No. 11, pp. 17–20; November, 1949.) Two applications of the principles of reaction are first outlined and two microphone circuits then described. The first circuit comprises a microphone of any type that may act as a variable impedance element in an oscillatory circuit, a high-frequency oscillator, a special type of quartz discriminator, and a frequency stabilizer. Using a capacitor microphone the low-frequency output available is of the order of 1 v compared with the normal 10–100 mv. The second arrangement is a reaction system using a carbon microphone coupled mechanically to a telephone earpiece. This can give either a considerable increase in sensitivity or in fidelity.

621.395.625+534.862.3/.4 539
Some Factors Governing the Choice of a High-Quality Recording and Reproducing System—G. F. Dutton. (*Proc. I.R.E.* (Australia), vol. 10, pp. 269–275; October, 1949.) A general discussion of the advantages and limitations of film recording, the Philips-Miller system (mechanically engraved variable-area film), disc systems and magnetic-tape systems.

621.395.625.2 540
Modern Practice in Disc Recording—R. V. Southey. (*Proc. I.R.E.* (Australia), vol. 9, pp. 16–20; November, 1948.) A general survey, with special reference to needle-tip and groove dimensions, cross-over frequency, and frequency correction. Recommended tip and groove dimensions for standardization are noted.

621.395.625.2:534.86 541
Some Problems of Disc Recording for Broadcasting Purposes—F. O. Viol. (*Proc. I.R.E.* (Australia), vol. 10, pp. 42–47; February, 1949.) The advantages of disc recording are outlined and the best compromise for groove spacing and velocity and direction of cut for 16-in discs is discussed. A recommended recording characteristic for general use is given. Recording heads and pickups suitable for cellulose-nitrate discs are also considered.

621.396.619.23:621.396.615.11 542
Warbler for Beat-Frequency Oscillator—Flanagan. (*See* 590.)

621.396.645 543
Description and Analysis of a New 50-Watt Amplifier Circuit—McIntosh and Gow. (*See* 592.)

621.396.645.37 544
The Cathode Follower as Audio Power Amplifier—Sterling. (*See* 599.)

681.84 545
Designing a Portable Sound Projector—G. A. del Valle. (*Elec. Mgf.*, vol. 44, pp. 74–79, 188; August, 1949.) The RCA 400 Junior model, for use with 16-mm sound film, weighs only 46 lb with its loudspeaker. The sound amplifier has four stages, with inverse feedback, and gives up to 10 w sound output with less than 2 per cent distortion, while frequency response varies by less than 5 db over the range 50–5,000 cps. An intensity of 150 lumens is obtained on the screen, using a standard 1,000-w lamp with forced-air cooling. The apparatus gives a class-room performance comparable with professional cinema standards and it does not require a skilled operator.

681.85 546
Some Aspects of Phonograph Pickup Design—W. R. Nicholas. (*Proc. I.R.E.* (Australia), vol. 10, pp. 63–73; March, 1949. Correction, vol. 10, p. 113.) A brief review is given of the properties of lateral disc records. The electrical and mechanical requirements to be met by a pickup are stated and a general treatment of the design of a typical magnetic pickup is given. The forces likely to be encountered at the stylus point are discussed and calculations are made for a particular type of magnetic pickup. Improved types are briefly described and their principal characteristics noted.

ANTENNAS AND TRANSMISSION LINES

621.315.212:621.395+621.397 547
Progress in Coaxial Telephone and Television Systems—Abraham. (*See* 739.)

621.392.22+621.392.26† 548
A General Method of Solution for Non-Uniform Cylindrically Symmetrical Wave Fields—H. H. Meinke. (*Z. Angew. Phys.*, vol. 1, pp. 509–516; October, 1949.) Continuation of 1645 of 1948. The frequency dependence of the permeability μ of the dielectric in the transformed system is determined by the Fourier coefficients in the expression for μ. To a first approximation the permeability increases as the square of the frequency. The wave field of a cylindrically symmetrical non-uniformity can be determined as soon as the electrostatic field distribution for the transformed system and its equipotential lines are known.

621.392.22:621.3.09 549
Contribution to the Study of Propagation on a Heterogeneous Line—F. H. Raymond. (*Jour. Phys. Radium*, vol. 7, pp. 171–177; June, 1946.) Methods of solving the equations of propagation, due to Parodi (2149 of 1944) and to Raymond (2472 of 1946), are discussed. The coefficients of reflection and transmission are defined for the general case, and a solution is obtained by means of series. Steady-state conditions are considered; Laplace transformations can be used to apply the results obtained to transient conditions. The method of treatment is applicable to coaxial cables with irregularities which may give rise to echo signals, and to propagation in heterogeneous media.

621.392.26† 550
The Field in Non-Uniform Rectangular Waveguides with H_{10}-Wave Excitation—R. Piloty, Jr. (*Z. Angew. Phys.*, vol. 1, pp. 490–502; October, 1949.) Continuation of 31 of February. An approximation method of solution of the general equation is developed. See also 548 above.

621.392.26† 551
On the Input Impedance of a Waveguide beyond its Cut-Off Frequency—A. Briot. (*Compt. Rend. Acad. Sci.* (Paris), vol. 229, pp. 1066–1068; November 21, 1949.) Bromwich's differential equation for the em field can be simplified in the case of a piston attenuator, the excitation being longitudinal and periodic. Formulas are obtained for the impedance for both electric and magnetic modes. The input impedance of a piston attenuator is imaginary, whatever the mode considered. It is capacitive for electric modes and inductive for magnetic modes. Since the characteristic impedance of a waveguide is a real quantity, a dissipative element should be placed in front of the attenuator to absorb reflected energy.

621.392.26†:621.392.43:621.396.615.141.2 552
Determination of the Characteristics of Matching Circuits for a Magnetron Modulator—J. Ortusi and P. Fechner. (*Ann. Radioélec.*, vol. 4, pp. 295–314; October, 1949.) The characteristic impedances of waveguides are calculated for different types of wave, and the conditions for suppression of the stationary waves caused by the insertion of an active obstacle in the waveguide are considered in detail. A method is described for measurement of the reflection, transmission, and loss characteristics of an active obstacle in a waveguide and, for the case of a magnetron modulator, the conditions are determined which are necessary for the greatest possible variation of the impedance thrown back by the magnetron into the waveguide. See also 894 of 1949 (Gutton and Ortusi) and 2140 of 1949.

621.396.67 553
Fundamental Limitations of Small Antennas—H. A. Wheeler. (*Proc. I.R.E.* (Australia), vol. 10, pp. 47–52; February, 1949.) Reprint. See 1261 of 1948.

621.396.67 554
Radiation Patterns and Gain of a Four-Antenna Array located at the Corners of a Square around a Central Parasitic Antenna—G. Boudouris. (*Jour. Brit. I.R.E.*, vol. 9, pp. 427–439; December, 1949.) Analysis assuming all are $\lambda/4$ antennas grounded to a perfectly conducting plane. The impedance at the base of each antenna is calculated as a function of the length of the diagonal, and the horizontal and vertical radiation patterns are determined. These may have directional characteristics. By comparing the field produced by the array to the field produced by a single antenna for the same power input, the average increase in field is found as a function of the diagonal spacing. The maximum average increase is 20 per cent and the maximum peak increase in certain directions 60 per cent. The effect of limited ground conductivity and the use of radiators shorter than $\lambda/4$ are discussed.

621.396.67 555
Helical Beam Antenna Design Techniques—J. D. Kraus. (*Communications*, vol. 29, pp. 6–9, 35; September, 1949.) Approximate formulas are derived for beam width, power gain, axial ratio and terminal resistance of a helix radiating in the axial mode, with angle of pitch

between 12° and 15°. The smaller angle gives a sharper main lobe for given axial length, while the larger angle gives a slightly smaller resistance variation throughout the frequency band.

621.396.67:621.392.43 556
Impedance Transformation in Folded Dipoles—R. Guertler. (*Proc. I.R.E.* (Australia), vol. 10, pp. 95–100; April, 1949.) The impedance of a folded dipole, relative to that of a simple dipole, may be adjusted by the use of conductors of different diameters for the separate elements. Increased impedance ratios can be obtained by the use of additional elements. Approximate formulas are developed for calculating the impedance ratio when the current ratio is known. Measurements confirm the practical applicability of the formulas.

621.396.67:621.397.62 557
Quadrature Phased TV Receiving Antenna—(*Tele-Tech*, vol. 8, pp. 36–37; November, 1949.) A capacitive phase shifter, with combined resistive and inductive detuning compensation, is used with two crossed horizontal dipoles to provide variable directivity without rotation of the antenna system. Orientation of one dipole can be used to minimize ghost effects. An outdoor and a built-in system are described. The whole U. S. television band is covered without switching.

621.396.671 558
The Predetermination of Antenna Characteristics by Means of Models—R. D. Boadle. (*Proc. I.R.E.* (Australia), vol. 10, pp. 155–159; June, 1949.) Paper presented at the Australian IRE convention, Sydney, 1948. Description of equipment and tèchnique, with results for a high-gain vertically polarized vhf antenna.

621.396.67:621.396.9 559
Radar Scanners and Radomes [Book Review]—Cady, Karelitz, and Turner (*See* 651.)

CIRCUITS AND CIRCUIT ELEMENTS

534.42+538.561 560
Production and Observation of High Frequencies due to Combination of Several Low Frequencies—S. Dolinski. (*Compt. Rend. Acad. Sci.* (Paris), vol. 229, pp. 812–814; October 24, 1949.) Suitable methods are described for audio and radio frequencies.

621.3.015.33:621.392 561
Response of Circuits to Steady-State Pulses—D. L. Waidelich. (PROC. I.R.E., vol. 37, pp. 1396–1401; December, 1949.) "A method of calculating the steady-state response of circuits to repeated pulses is given using the method of the steady-state operational calculus. A short table of transforms which have been found useful in these calculations is also presented. The response of several basic circuits to these pulses is obtained and shown as calculated curves, and the calculated curves are then compared with curves obtained experimentally. These curves have been found to be very useful in adjusting circuits to be used with pulses. Several other possible applications are discussed."

621.314.2:621.396.611.33/.34 562
A Design for Double-Tuned Transformers—J. B. Rudd. (*Proc. I.R.E.* (Australia), vol. 10, pp. 3–9; January, 1949.) 1948 Australian I.R.E. Convention paper. See 3063 of 1949.

621.314.3† 563
An Experimental Study of the Magnetic Amplifier and the Effects of Supply Frequency on Performance—E. H. Frost-Smith. (*Jour. Brit. I.R.E.*, vol. 9, pp. 440–443; December, 1949.) Discussion on 44 of February.

621.314.3† 564
On the Dynamics of the Self-Excited Series Transductor—M. Delattre and K. Kühnert. (*Compt. Rend. Acad. Sci.* (Paris), vol. 229, pp. 819–821; October 24, 1949.) Discussion for the period of transition from one steady state to a different one when the control current is changed. The response time depends on the absolute value of the input signal and on various other factors; it approaches zero under ideal conditions.

621.314.3† 565
Self-Saturation in Magnetic Amplifiers—W. J. Dornhoefer. (*Elec. Eng.*, vol. 68, p. 988; November, 1949.) Summary of AIEE paper. A high voltage can be induced in the control winding if one ac coil becomes inoperative and the effective inductance and time delay of the control circuit are substantial, but these factors can be reduced either by external feedback or by self-saturation. The latter method makes use of a rectifier tube in series with each ac (anode) winding; its advantages are discussed; it has been applied for both ac and dc output and for single and polyphase supplies. Rectifiers with high backward/forward resistance ratio are required.

621.317.772 566
Diode Phase-Discriminators—R. H. Dishington. (PROC. I.R.E., vol. 37, pp. 1401–1404; December, 1949.) "Two sinusoidal phase-discriminators are analyzed and it is found that universal curves of their general phase characteristics can be plotted as a function of two parameters. From these curves it is concluded that the resistances in series with the tubes and also the tube resistances themselves are the most important factors in determining optimum performance."

621.318.4:621.397.62 567
Coils for Television Receivers—F. Juster. (*Télévis. Franç.*, No. 53, pp. 15–18, 24; November, 1949.) Graphical methods for designing high-frequency, intermediate-frequency, and video-frequency coils with maximum Q.

621.318.42 568
On the Calculation of Effective Core Permeability of Premagnetized Choke Coils—J. Kammerloher. (*Funk. und Ton.*, vol. 3, pp. 491–496; 1949.) Continuation of 29 of 1949. Values obtained when differential permeability is replaced by reversible permeability are in good agreement with those of Feldtkeller.

621.318.7 569
The Theory of Electric Filters and the Polynomials of Tchebycheff—A. Colombani. (*Jour. Phys. Radium*, vol. 7, pp. 231–243; August, 1946.) Full paper; for abstract of shorter version see 652 of 1947.

621.392 570
Quarter Wave Networks—E. Green. (*Marconi Rev.*, vol. 12, pp. 157–171; October and December, 1949.) The properties of a normal $\lambda/4$ line are derived by means of vector diagrams and the following basic equations used to express any form of $\lambda/4$ or inverting network:

$$I_1=jV_2/R_0;\ V_1=jR_0I_2.$$

I_1, V_1 and I_2, V_2 are respectively the input and output current and voltage and R_0 is the surge impedance of the $\lambda/4$ line. It is proved that certain types of lumped network are identical as regards external relations. The component values and characteristic impedances of various balanced and unbalanced networks are tabulated. An appendix deals with the derivation of different forms of a bridge network devised by A. T. Starr for operation between balanced and unbalanced lines. This derivation is based on that given by Starr in an unpublished memorandum.

621.392.43:621.396.67 571
Design Procedures for Pi-Network Antenna Couplers—L. Storch. (PROC. I.R.E., vol. 37, pp. 1427–1432; December, 1949.) "The design of reactive pi networks for transforming a wide range of complex load impedance into a fixed resistance shunted by a tuned circuit is subjected to a thorough investigation. A very significant result is the complete analogy which is established between the analysis and design of the pi network and the equivalent manipulation of a group of simple geometrical figures."

621.392.5 572
Realization of Linear Quadripoles with Prescribed Frequency Dependence, taking account of Equal Coil and Capacitor Losses—Nai-Ta Ming. (*Arch. Elektrotech.*, vol. 39, pp 496–507; 1949.) See also 3367 of 1949.

621.392.5 573
Resistance Quadripoles as Attenuator Elements—W. Taeger. (*Funk. und Ton.*, vol. 3, pp. 475–487; 1949.) Calculations of various impedance ratios in T, L, Π and bridged-T networks. Attenuation in nepers is tabulated and plotted for different values of R/Z.

621.392.5 574
On the Synthesis of the Most General Passive Quadripoles—V. Belevitch and R. Leroy. (*Câbles and Transmission* (Paris), vol. 3, pp 340–341; October, 1949.) Comment on 1886 of 1949 and author's reply.

621.392.52 575
General Forms of Ladder-Filter Half-Sections Classed According to the Value of the Image-Impedance Transfer Index—J. E. Colin. (*Câbles and Transmission* (Paris), vol. 3, pp. 281–293; October, 1949.) Continuation of 2748 of 1949. Different simple and compound types of ladder-filter network with one or two cutoff frequencies are reduced to eight basic forms, whose principal characteristics are discussed. Formulas for impedance ratio, component values, and image-impedance are tabulated, and three general laws of form are enunciated.

621.392.52 576
Transference Nomographs for Low-Pass Iterative Filters—E. W. Tschudi. (*Electronics*, vol. 22, pp. 112, 114; December, 1949.) For determining time constant and phase lag, given input frequency, attenuation and number of stages up to 6.

621.392.52 577
Using the Reactance Chart for Filter Design Problems—H. B. Davis. (*Audio Eng.*, vol. 33, pp. 12–13, 40; December, 1949.) Methods are outlined for determining the values of components of various filter and equalizer circuits.

621.392.52 578
Filters: Part 1—The Importance of Z_0, the Characteristic Impedance—"Cathode Ray." (*Wireless World*, vol. 56, pp. 25–29; January, 1950.)

621.392.52:621.395.44:621.316.1 579
Wave Filters protect Carrier Signals from Shunting Effect of Capacitors—W. A. Ringger, Jr. (*Elec. World*, vol. 132, pp. 106–108; November 19, 1949.) High-voltage wave filters using various parallel and series resonant-circuit

combinations preserve carrier voltages and suppress spurious voltages associated with carrier operation on distribution systems.

621.395.667 580
Equalizer Charts—(*Bell Sys. Tech. Publ. Monogr.* B-1643, 15 pp.) Loss and phase of series, shunt, and bridged-T equalizers are given in decibels and degrees.

621.396.611 581
Contribution to the Theory of the Mathematical Treatment of Nonlinear Phenomena—H. Rosenhamer. (*Bull. Schweiz. Elektrotech. Ver.*, vol. 40, pp. 5–18; January 8, 1949. In German.) A method is given for the solution of the general equation of order n applicable to nonlinear electrical phenomena. The equation is reduced to the sum of products of linear differential quotients with functional coefficients, which are then replaced successively by suitably chosen constants and the integration carried out by normal methods. The solution thus obtained only satisfies the original equation approximately, but can be used to determine fresh values of the functional coefficients giving a better solution. The method is applied to the study of an *LCR* circuit to which a sinusoidal voltage is applied.

621.396.611.1 582
Some Theoretical Considerations and Experiments on Oscillation Phenomena in Circuits with Nonlinear Elements—G. J. Elias and S. Duinker. (*Tijdschr. ned. Radiogenool.*, vol. 14, pp. 163–191; November, 1949. In Dutch, with English summary.) The solutions of the equation

$$\ddot{y}+y+\nu y^3=\alpha \cos (px+\phi)$$

are discussed. They include periodic solutions giving a fundamental frequency which is a submultiple of the generator frequency.

For free vibrations, the period can be expressed as an elliptic integral; for forced vibrations, an extension of this expression is given and the stability of the solution is discussed. If the emf is varied continuously, several discontinuities must occur if a periodic forced vibration, of the fundamental or a subharmonic frequency, is to be sustained. The effect of adding any number of odd powers of y to the left-hand side of the differential equation is also considered; the expression for the period then becomes a hyperelliptic function. Experiments which confirm the theory are described; oscillograms of subharmonic vibrations are shown.

621.396.611.1 583
Resonant Circuits with Time-Varying Parameters—R. H. Kingston. (PROC. I.R.E., vol. 37, pp. 1478–1481; December, 1949.) An approximate solution of the differential equation, with an error criterion giving the limits of accuracy of the solution.

621.396.611.4 584
Analogue Studies of Losses in Reflex Oscillator Cavities—F. W. Schott and K. R. Spangenberg. (PROC. I.R.E., vol. 37, pp. 1409–1418; December, 1949.) "An analysis is made which shows the method of applying the network analogue to the investigation of the effects of dielectric and wall losses on cavity-resonator behavior.

"The Q and shunt resistance of re-entrant cavities operating in the first- and second-order TM_0 type modes are investigated. The condition for a zero of shunt resistance is determined. Experimental results are discussed."

621.396.615 585
The Breadth of the Pulling-In Range of a Self-Excited Valve Generator controlled by an Integral Multiple of its Natural Frequency—H. Kanberg. (*Funk. und Ton.*, vol. 3, pp. 497–505; 1949.) Analysis showing how the frequency range may be determined from the Lissajous figure displayed on a cro.

621.396.615 586
The Transitron Effect and its Applications—J. Moline. (*Radio Franç.*, no. 11, pp. 21–24; November, 1949.) Distinction is made between the dynatron effect in a tetrode and the transitron effect in a pentode, and a simple explanation of transitron operation is given. The characteristics of some typical tubes operating as transitrons are noted, and applications of the transitron effect to the maintenance of sinusoidal or of relaxation oscillations are considered.

621.396.615:621.396.611.32 587
Phase-Shift Oscillators with Very Tight Coupling—M. Soldi. (*Radio Tech. Dig.* (Franç), vol. 3, pp. 353–363; December, 1949.) French version of 2757 of 1949, with the addition of a comprehensive bibliography.

621.396.615.17/.18 588
High-Ratio Multivibrator Frequency Divider—M. Silver and A. Shadowitz. (*Proc. I.R.E.* (Australia), vol. 10, pp. 256–258; September, 1949.) Reprint. See 52 of 1949.

621.396.615.17:621.317.755 589
A Slow-Sweep Time-Base—V. H. Attree. (*Jour. Sci. Instr.*, vol. 26, pp. 257–262; August, 1949.) The requirements of time bases suitable for sweep durations of the order 100–10 ms are discussed with special reference to the use of triggered multiple sweeps. Flyback time can be made as little as one thousandth of the scan time. The circuit described is direct-coupled throughout, and linear traces of identical velocity and duration are generated irrespective of the nature of the triggering wave. The time base is unaffected by any trigger pulses which may occur during sweeping.

621.396.619.23:621.396.615.11 590
Warbler for Beat-Frequency Oscillator—J. L. Flanagan. (*Electronics*, vol. 22, pp. 93–95; December, 1949.) A new reactance tube circuit giving FM of about ± 10 per cent without accompanying AM, for use with a standard beat-frequency audio oscillator. Instead of using a capacitor to couple anode and grid, the grid is earthed, and the capacitor is connected between anode and cathode, a degenerative resistance being introduced between cathode and earth. The theoretical expression for the input impedance shows that its resistive component is independent of g_m.

621.396.645 591
A Contact-Modulated Amplifier and Some of its Laboratory Uses—J. F. Lash. (*Science*, vol. 110, pp. 374–375; October 7, 1949.) A dc signal, converted to 80-cps ac by a mechanical interrupter, is stepped up in voltage by a transformer followed by several tube-amplifier stages and finally rectified by a second interrupter synchronized with the first. This system enables dc signals of a few hundredths of a microvolt to be measured.

621.396.645 592
Description and Analysis of a New 50-Watt Amplifier Circuit—F. H. McIntosh and G. J. Gow. (*Audio Eng.*, vol. 33, pp. 9–11, 40; December, 1949.) A circuit is described which eliminates the distortion present in conventional push-pull amplifiers operating between class A and class B, due to leakage reactance between the primary windings. A high ratio (>200,000 to 1) of primary inductance to leakage reactance is obtained by winding the two primaries together in a bifilar manner. Circuit details and performance characteristics are given. A 50-w output is obtained at frequencies from 20 cps to 20 kc with less than 1 per cent harmonic or intermodulation distortion.

621.396.645 593
Grounded-Grid Power Amplifiers—P. A. T. Bevan. (*Radio Tech. Dig.* (Franç), vol. 3, pp. 323–339; December, 1949.) French version of 2763 of 1949, with the addition of a comprehensive bibliography.

621.396.645 594
Wide-Band Chain Amplifier—F. Kennedy and G. Rudenberg. (*Elec. Mfg.*, vol. 44, pp. 56–59, 168; November, 1949.) The amplifier operates on the traveling-wave principle; a series of tubes have their grids connected to one delay line and their anodes to another. The forward waves produced in the lines augment each other and the backward waves are absorbed by the anode resistors. Six tubes are used in an amplifier with a constant gain of 20 db over the range 200 kc–200 Mc. Undistorted output is obtained up to 4 v and the SWR is greater than 1.5 db. Design and construction details are given; the importance of careful layout to avoid stray capacitance and inductance is stressed.

621.396.645:621.385.029.63/.64 595
200-Mc/s Traveling-Wave Chain Amplifier—H. G. Rudenberg and F. Kennedy. (*Electronics*, vol. 22, pp. 106–109; December, 1949.) A brief descriptive account of a wide-band amplifier consisting of several tubes whose grids are fed from taps on a terminated artificial line consisting of a series of inductors connected between the grid shunt capacitors. The output is taken from the end of a similar line joining the anodes. Particular examples and some refinements are discussed. The optimum gain per chain is 2.718. Any further gain should be obtained by connecting such chains in series. Such a design is most economical in tubes.

621.396.645.029.4/.52:621.396.822 596
Selective Amplification at Low Frequencies—L. de Queiroz Orsini. (*Onde Élec.*, vol. 29, pp. 408–413 and 449–456; November and December, 1949.) Discussion of voltage amplifiers with narrow pass band, for frequencies between 2 cps and 50 kc. Feedback circuits are described for frequencies near 500 cps, and parallel-T circuits for very low frequencies. Flicker effect and other tube and circuit noise, and methods of reducing it, are also considered.

621.396.645.211 597
Theory of Resistance-Amplifier Stage—W. Druey. (*Bull. Schweiz. Elektrotech. Ver.*, vol. 40, pp. 49–51; January 22, 1949. In German.) A derivation of the gain formula from a consideration of equivalent circuits.

621.396.645.35 598
Stabilizing a Wide-Band D.C. Amplifier—A. J. Williams, Jr., W. G. Amey, and W. McAdam. (*Elec. Eng.*, vol. 68, p. 934; November, 1949.) Summary of AIEE paper. The problem of zero stabilization in dc amplifiers with negative feedback is discussed. A comparison of input with output divided by gain can be used to indicate zero disturbance, whether a signal is present or not. The comparison voltage is applied to a correcting circuit using a contact-modulated dc amplifier and integrator. Zero correction to within a fraction of a microvolt is thus obtained in less than 0.005 sec.

621.396.645.37 599
The Cathode Follower as Audio Power

Amplifier—H. T. Sterling. (*Audio Eng.*, vol. 33, pp. 14–15, 29; December, 1949.) As an output stage, the cathode follower is a feedback amplifier with special characteristics which can be provided equally well by conventional amplifier circuits.

621.396.662.029.64:621.392.26† 600

Microwave Attenuators—R. Malvano. (*Elettronica and Televisione* (Turin), vol. 4, pp. 221–226; September, 1949. French version in *Radio Tech. Dig.* (Franç), vol. 3, pp. 369–374; December, 1949.) A general discussion with particular reference to waveguide attenuators. A description of an experimental attenuator made at the Istituto Elettrotecnico Nazionale Galileo Ferraris, Turin, is included.

GENERAL PHYSICS

535.3 601

On the Attenuation of Plane Waves by Obstacles of Arbitrary Size and Form—H. C. van de Hulst. (*Physica,'s Grav.*, vol. 15, pp. 740–746; September, 1949. In English.) The extinction cross section of any obstacle is -2λ times the imaginary part of the amplitude function for forward scattered light. This relation holds for any size, shape or composition of the obstacle, and may be applied to light, sound, and electron scattering. It may be generalized to include polarization effects. Examples are discussed.

537.311.62:621.318.4 602

Study of the H.F. Resistance of a Stranded Wire Coil—A. Colombani. (*Jour. Phys. Radium*, vol. 10, pp. 285–294; October, 1949.) Starting from Maxwell's equations and assuming the radius of the strand to be less than the depth of penetration of the current, a simple formula is derived for high-frequency resistance. The formula is in agreement with the calculations of Sommerfeld and with measured values. Its application to different problems is illustrated and shows that there is an optimum resistance and form of coil in each case. For frequencies above 3 Mc, solid wire is preferable to stranded wire, for which the losses in the enamel insulation of the strands become important.

537.533:538.569:621.396.822 603

Fluctuation Phenomena arising in the Quantum Interaction of Electrons with High-Frequency Fields—D. K. C. MacDonald and R. Kompfner. (PROC. I.R.E., vol. 37, pp. 1424–1426; December, 1949.) Quantum-mechanical analysis of the interaction of an electron beam with an oscillating resonant cavity is applied to determine the fluctuations in energy flow in the beam. Comparison of the expressions for the classical and quantal cases indicates that, under extreme limiting conditions of operation, a difference might just be perceptible.

537.581:621.385.032.213 604

Thermionic Electron Emission from Carbon—H. F. Ivey. (*Phys. Rev.*, vol. 76, p. 567; August 15, 1949.) Values of the electronic work function ϕ, the Richardson constant A, and the emission current density are given for a carbon filament after heating to 2,500° K. $\phi=4.60$ ev and $A=46$ amp/cm² degree². The values of current density at 1,500° K and 2,000° K are 0.039 μamp/cm² and 0.50 mamp/cm² respectively, which are lower than the values found by other investigators.

538.3 605

The Application of Maxwell's Second Law—H. Kafka. (*Elektrotechnik* (Berlin), vol. 3, pp. 353–358; November, 1949.) A distinction between the mathematical expression and the physical interpretation of the laws of induction.

538.51 606

Electromagnetic Induction in a Rotating Sphere—E. C. Bullard. (*Proc. Roy. Soc. A*, vol. 199, pp. 413–443; December 7, 1949.) An account is given of the induction of electric currents in a rotating, conducting sphere surrounded by and in contact with a concentric, stationary, conducting shell of any thickness. The currents and associated mechanical couples induced by various constant fields are discussed and the freely decaying modes are studied. The modes involving toroidal magnetic fields are of most interest and may be important in terrestrial magnetism. Induction in an oscillating sphere is briefly discussed.

538.56:537.71 607

On the Resistance of Electromagnetic Waves—C. Budeanu. (*Rev. Gén. Élec.*, vol. 58, pp. 481–484; November, 1949.) This resistance could be given different values according as the classical or the rationalized system of units is used. The precautions necessary in expressing this quantity and the value it should be given are considered.

538.566:[537.562+537.525.92 608

Wave Amplification by Interaction with a Stream of Electrons—J. A. Roberts. (*Phys. Rev.*, vol. 76, pp. 340–344; August 1, 1949.) Discussion of the propagation of plane em waves in a uniform ionized medium in which the electrons have a mean drift velocity. The treatment is based on Bailey's general theory (2785 and 3406 of 1949). For frequencies below a critical frequency of the same order as the electron plasma frequency, one of the eight waves possible in general grows in amplitude as it progresses through the medium. The relation of this result to theories of solar noise and of the traveling-wave amplifier is discussed.

538.569.4 609

Absorption of Ultra High-Frequency Radio Waves in Organic Liquids—S. C. Sirkar and S. N. Sen. (*Nature* (London), vol. 164, pp. 1048–1049; December 17, 1949.) Acetone shows an absorption peak at about 400 Mc and glycerine at about 500 Mc for a temperature of 31° C. Absorption curves for these and other liquids are given and discussed.

GEOPHYSICAL AND EXTRATERRESTRIAL PHENOMENA

016:550.3 610

List of Recent Publications—H. D. Harradon. (*Jour. Geophys. Res.*, vol. 54, pp. 308–314; September, 1949.) Subjects covered include terrestrial magnetism and electricity, cosmic rays, upper-air research, and the earth's crust and interior.

061.3:551.510.535:538.566 611

The Conference on Ionospheric Research—(*Jour. Geophys. Res.*, vol. 54, pp. 281–294; September, 1949.) Summaries of symposia and abstracts of papers presented at the conference held at Pennsylvania State College under joint sponsorship of that College and of the Geophysical Research Directorate, U.S.A.F., June 27–29, 1949. Selected papers are noted below, in this section or in the 'Propagation of Waves' section.

523.32:621.396.822 612

Microwave Thermal Radiation from the Moon—J. H. Piddington and H. C. Minnett. (*Aust. Jour. Sci. Res., Ser. A*, vol. 2, pp. 63–77; March, 1949.) Measurements have been made in a 15-Mc band centered at 24 kMc. The average temperature over the lunar disc varies sinusoidally between 198.7° K and 279.3° K, with a phase lag behind the lunar phase angle of about 45°. The discrepancy with previous measurements at long infrared wavelengths is explained in terms of radiation from subsurface layers which are partially transparent to 24-kMc waves. Results are consistent with the existence of a thin layer of dust covering a solid lunar surface. The temperature of the disc of the new moon is estimated at 156° K, and that of the deep interior at 241° K.

523.53:621.396.9 613

A Study of Radio Reflections from Meteor Trails in Research on the Upper Atmosphere—A. G. McNish. (*Jour. Geophys. Res.*, vol. 54, p. 285; September, 1949.) Summary of Pennsylvania State College Conference paper. Discussion of radio research on meteors in progress at CRPL, with special reference to the investigation of ionic processes in the upper atmosphere. Experimental equipment consists of two 10-kw pulse transmitters operating continuously on 27.2 and 40.4 Mc. Signals reflected from the ionized trail left by the meteor are recorded on pen-and-ink tape and on photographic film. Results already obtained indicate clearly that meteors are not responsible for most of the E_s reflections ordinarily obtained by vertical-incidence recorders. Two possible mechanisms of reflection are considered and an experimental method for discriminating between them is suggested.

523.72+523.854]:621.396.822 614

Solar and Galactic R.F. Radiation—M. Laffineur. (*Onde Élec.*, vol. 29, pp. 402–407; November, 1949.) A general survey of recent work; results obtained by various authors are compared graphically. A solar disturbance observed at Meudon on March 26, 1949, is discussed. Other such disturbances were noted in 698 and 3129 of 1949. See also 2777 of 1948 (Lehmann).

523.72:621.396.11 615

Observations of the Propagation of Broadcasting Waves, λ=1250 m, during the Occurrence of Mögel-Dellinger Effects—Lauter. (*See* 716.)

523.72:621.396.822 616

Solar Radiation at 1200 Mc/s, 600 Mc/s and 200 Mc/s—F. J. Lehany and D. E. Yabsley. (*Aust. Jour. Sci. Res., Ser. A*, vol. 2, pp. 48–62; March, 1949.) Daily observations made between August 18 and November 30, 1947, are described. The characteristics of the radiation at 200 Mc were in general agreement with other observations. At 600 and 1,200 Mc the received intensity showed long-term variations over a range of about 2:1. "The radiation received when the sun was almost free of sunspots corresponded to an effective black-body temperature of 0.5 million °K at 600 Mc and 0.1 million °K at 1,200 Mc. As sunspots appeared, the temperature rose and showed marked correlation with sunspot area. It is considered that radiation at these frequencies is entirely thermal in origin and that the long-period variations are at least partly due to the influence of the magnetic field of sunspots on the mechanism of thermal emission from a magneto-ionic medium. On a few occasions, isolated disturbances were observed on 600 Mc and 1,200 Mc, some of which were associated with chromospheric flares and radio fade-outs. The difficulties arising in the calibration of the apparatus and the steps taken to overcome them are discussed in detail."

523.746:523.752 617

Hall Currents and the Ejection of Prominences by Sunspots—R. G. Giovanelli. (*Aust. Jour. Sci. Res., Ser. A*, vol. 2, pp. 39–47; March, 1949.) A theoretical explanation of the occurrence of eruptive prominences in the neighborhood of a chromospheric flare. Localized regions of large space charge occur

because of the relatively low conductivity perpendicular to lines of magnetic force. Large electric fields are thus set up normal to the magnetic field, and both positive and negative charges drift in the same sense in a direction at right angles to the crossed fields, giving rise to a general movement of the gas. The drift velocities appear to be comparable with those found in prominences. See also 78 and 376 of 1949 and 357 of March.

523.746"1949.04/.06" 618
Provisional Sunspot-Numbers for April to June 1949—M. Waldmeier. (*Jour. Geophys. Res.*, vol. 54, p. 300; September, 1949.)

523.75:551.510.535 619
Ionospheric Effects of Solar Flares, 1948—C. E. H. Rydbeck, and D. Stranz. (*Chalmers Tekn. Högsk. Handl.*, No. 83, 16 pp.; 1949. In English.) Regular recordings of such effects with different kinds of apparatus were started at the Chalmers University Geophysical Observatory early in 1948. The results of the first half-year are discussed in this preliminary report. The statistical distribution across the solar disc of radiation sources giving rise to a greater or less degree of fading of radio signals is shown. The magnitude and probability of the absorption of the ultraviolet fade-out radiation in the solar corpuscular beam is discussed.

550.38"1949.01/.03" 620
International Data on Magnetic Disturbances, First Quarter, 1949—(*Jour. Geophys. Res.*, vol. 54, pp. 295–299; September, 1949.) Continuation of 3418 of 1949 in revised form, with explanation of new symbols and abbreviations. The original K-index is replaced by a planetary 3-hour range index K_p. Additional preliminary data on sudden commencements and solar flare effects (crochets) are included.

550.38"1949.04/.06" 621
Cheltenham [Maryland] Three-Hour-Range Indices K for April to June, 1949—P. G. Ledig. (*Jour. Geophys. Res.*, vol. 54, p. 300; September, 1949.)

550.384 622
The K-Index of Geomagnetic Activity at Eskdalemuir, 1940–47—J. Crichton. (*Jour. Geophys. Res.*, vol. 54, pp. 275–276; September, 1949.) Discussion of the relative importance of horizontal intensity H, declination ν, and vertical intensity V as the determining factor in the assignment of K-indices, and of the diurnal and seasonal incidence, and recurrence tendencies, of occasions when D or V was the determining factor.

550.385"1949.01/.06" 623
Principal Magnetic Storms [Jan.-June 1949]—(*Jour. Geophys. Res.*, vol. 54, pp. 301–302; September, 1949.)

551.510.5:551.524.7 624
Tropopause Fluctuations due to High-Reaching Influxes of Cold Air—W. Hesse. (*Z. Met.*, vol. 3, pp. 129–135; May and June, 1949.) Discussion of the connection between variations of the temperature at the tropopause and in the upper troposphere and lower stratosphere.

551.510.52:546.214:551.524.7 625
Total Ozone Related to Troposphere Temperatures—(*Tech. Bull. Nat. Bur. Stand.*, vol. 33, pp. 128–129; November, 1949.) Long-term measurements of the ultraviolet radiation reaching the earth from the sun reveal a correlation between the temperature of the air at an altitude of about 5 miles and the total amount of O_3 in the atmosphere.

551.510.535 626
Ionization of the Stratosphere over High- and Low-Pressure Regions of the Troposphere—G. Falckenberg and E. Lauter. (*Z. Met.*, vol. 3, pp. 136–140; May and June, 1949.) A statistical analysis of the results of 650 observations of the reflection of 1,250-m waves from the E-layer.

551.510.535 627
Calculation of the Absorption Decrement for a Parabolic Ionospheric Layer for the case of Vertical Incidence—É. Argence and K. Rawer. (*Compt. Rend. Acad. Sci.* (Paris), vol. 229, pp. 996–997; November 14, 1949.) The total absorption is the sum of three parts, the first (δ_1) being the attenuation which depends on the path length, the second (δ_2) the loss of energy due to collisions in the layer, and the third (δ_3) due to partial reflection by the sporadic-E layer. Formulas are obtained for δ_2 for the case of total reflection and for that of layer penetration; the influence of the earth's magnetic field is neglected. These formulas are of importance in the study of E-layer absorption, which cannot be neglected when working near the critical frequency. See also 3035 and 3879 of 1939.

551.510.535 628
Electron Production in the Ionosphere—R. Seeliger. (*Naturwissenschaften*, vol. 36, pp. 321–327; November, 1949. Bibliography, p. 327.) A study of conditions in the E layer.

551.510.535 629
True Heights of the F_2 Layer—G. R. White and I. S. Wachtel. (*Jour. Geophys. Res.*, vol. 54, pp. 239–242; September, 1949.) "The true heights of electron density for Washington were computed, using the parabolic method, for winter, summer, and equinox of 1945 at noon and at midnight. Representative curves were formed by combining the data from a large number of days." The distributions obtained show that the maximum electron density of the F_2 region occurs at a lower height at midday than at midnight. The curves are compared with similar curves for Huancayo, where the height of maximum electron density is greater at midday than at midnight.

551.510.535 630
Ionospheric Research in the U. S. Air Force—N. C. Gerson. (*Jour. Geophys. Res.*, vol. 54, pp. 286–287; September, 1949.) Summary of Pennsylvania State College Conference paper. Various experimental undertakings planned or in progress are briefly mentioned.

551.510.535 631
Ionospheric Research at the Pennsylvania State College—B. B. Underhill. (*Jour. Geophys. Res.*, vol. 54, pp. 287–288; September, 1949.) Summary of Pennsylvania State College Conference paper. An account of the history, organization, and research in progress at the Radio Propagation Laboratory.

551.510.535 632
Summary of a Meeting on Mathematical Problems in Ionospheric Research—N. C. Gerson. (*Jour. Geophys. Res.*, vol. 54, pp. 289–290; September, 1949.) Discussion following the Pennsylvania State College Conference. Ten of the major problems suggested for investigation are noted.

551.510.535 633
Sunrise Effects in F Region from High Speed Ionospheric Recordings—H. W. Wells. (*Jour. Geophys. Res.*, vol. 54, pp. 277–280; September, 1949.)

551.510.535:525.624 634
Tidal Effects in the F Layer—M. W. Jones and J. G. Jones. (*Phys. Rev.*, vol. 76, p. 581; August 15, 1949.) A periodic variation of the thickness of the F layer, noted at College, Alaska, was submitted to harmonic analysis. In addition to the diurnal change due to the sun's ionizing radiation, variations resulting from the contractions and expansions of the layer due to solar and lunar gravitational forces were noted. The lunar diurnal wave, whose amplitude varied from 0.1 to 1.6 times that of the solar semidiurnal tide during the winter of 1948–1949, can be explained by simple tidal theory.

551.510.535:525.624 635
Lunar Ionospheric Variations at Low-Latitude Stations—A. G. NcNish and T. N. Gautier. (*Jour. Geophys. Res.*, vol. 54, pp. 303–304; September, 1949.) Amplitudes and phase angles for variation in F_2-layer critical frequency at noon and 4 p.m. are tabulated for Huancayo, Christmas Island, and Leyte (near the geomagnetic equator), and Trinidad and Maui (about 20° from the geomagnetic equator). Results are given for solstices and equinoxes; the age of the moon is included. The phase reversal in the noon values at 20° with respect to 0° geomagnetic latitude may be associated with the equatorial trough in the latitude distribution of F_2-layer critical frequencies.

551.510.535:525.624 636
On the Practical Determination of Lunar and Luni-Solar Daily Variations in Certain Geophysical Data—K. K. Tschu. (*Aust. Jour. Sci. Res., Ser. A*, vol. 2, pp. 1–24; March, 1949.)

551.510.535:621.396.11 637
Summary of Symposia [at the Pennsylvania State College Conference]—A. H. Waynick. (*Jour. Geophys. Res.*, vol. 54, pp. 290–294; September, 1949.) The symposia covered (a) long-wave propagation, (b) the physical bases for the Appleton-Hartree dispersion equation, (c) studies of the auroral region, (d) ionospheric absorption, theory and measurement, and (e) tidal oscillations in the upper atmosphere.

551.510.535:621.396.11 638
The Effect of the Lorentz Polarization Term on the Vertical Incidence Absorption in a Deviating Ionosphere Layer—J. M. Kelso. (*Jour. Geophys. Res.*, vol. 54, p. 284; September, 1949.) Summary of Pennsylvania State College Conference paper. Appropriate assumptions and approximations are used to derive expressions for absorption and for group height by means of the Lorentz theory. The results are compared with those obtained by Hacke from the Sellmeyer theory. The determination of the value of the collisional frequency at the level of maximum ionization is discussed for both theories. See also 1050 of 1949 (Hacke and Kelso).

551.510.535:621.396.11 639
Sporadic Ionization at High Latitudes—Meek. (*See* 725.)

551.524+551.54 640
Atmospheric Pressure and Temperature Gradients over Central Europe—R. Höhn. (*Z. Met.*, vol. 3, pp. 148–153; May and June, 1949.)

551.594.5:621.396.11 641
Sky-Wave Observations ($\lambda = 1250$ m) during Displays of the Northern Lights in 1947—Lauter and Sprenger. (*See* 728.)

LOCATION AND AIDS TO NAVIGATION

621.396.9 642
The Use of Radar in the Ice-Breaker

Service—H. Larsson. (*Jour. Inst. Nav.*, vol. 2, pp. 315–323; October, 1949.) An RCA Type CR-101 radar set was used for the 3-cm band and a Raytheon Mariners' Path-finder for the 10-cm band. The type of echo received from various types of ice is described. Radar can be used to determine the ice-breaker's position from bearings on landmarks, to detect open-water channels in conditions of bad visibility, or to locate a ship whose position is only approximately known in the ice-breaker. The relative merits of the two wavelengths are discussed.

621.396.9:523.53 643
A Study of Radio Reflections from Meteor Trails in Research on the Upper Atmosphere—McNish (*See* 613.)

621.396.9:551.515.2 644
Industrial Radar for Hurricane Tracking—W. F. Gerdes and R. C. Jorgensen. (*Science*, vol. 110, pp. 357–360; October 7, 1949.) Hurricanes present a distinctive picture on a radar set because of the accompanying heavy rain. Modifications to a 10-cm radar set Type SCR-784, for hurricane observation near Freeport, Texas, are discussed.

621.396.933 645
High-Stability Radio Distance-Measuring Equipment for Aerial Navigation—H. Busignies. (*Proc. I.R.E.* (Australia), vol. 9, pp. 5–10; November, 1948.) Paper presented at the 1948 Australian I.R.E. conference, Sydney, and describing equipment noted in 1402 and 1944 of 1949.

621.396.933 646
Improved Radio Systems for Modern Aircraft—(*Tele-Tech*, vol. 8, pp. 31–33, 59; November, 1949.) Discussion of recent developments incorporating many PICAO recommendations (see 2436 and 3532 of 1947) and of distance measuring equipment, full use of which may be expected by 1953. See also 102 of February (Burgmann).

621.396.933 647
The Oboe System—P. Besson. (*Onde Élec.*, vol. 29, pp. 351–367 and 414–426; October and November, 1949.) A comprehensive description. See also 1790 of 1947. (Jones).

621.396.933 648
Pulse Navigation Systems—W. L. Barrow. (*Proc. I.R.E.* (Australia), vol. 10, pp. 276–282; October, 1949.) Paper presented at the International Meeting on Marine Radio Aids to Navigation, New York, 1947. Brief review of short-, medium-, and long-distance systems available at present, with discussion of the factors affecting their suitability for particular services.

621.396.933 649
Rotating-Field Radio Beacons for Navigation—S. Ostrovidow. (*Rev. Gén. Élec.*, vol. 58, pp. 469–473; November, 1949.) The general theory for this type of beacon is outlined and an installation near Marseilles is described. This operates on 3.965 Mc with modulation frequency of 1 kc. Antenna power is about 2 kw and the effective range above 500 km. Sources of error, in particular those due to the site, are discussed. Performance is considered to be comparable with that of the Decca and gee systems.

621.396.933(083.71) 650
Standards on Radio Aids to Navigation: Definitions of Terms, 1949—(PROC. I.R.E., vol. 37, pp. 1364–1371; December, 1949.) Prepared by an IRE committee.

621.396.9:621.396.67 651
Radar Scanners and Radomes [Book Review]—W. M. Cady, M. B. Karelitz, and L. A. Turner (Eds). Publishers: McGraw-Hill, New York and London, 1949, 491 pp., 42s. (*Nature* (London), vol. 164, pp. 1064–1065; December 24, 1949.) No. 26 of the M.I.T. Radiation Laboratory series. The book "deals mainly with the engineering aspects of the design of scanners and their housings . . . . There is almost no reference to equipment operating at wavelengths greater than 10 cm. and there is little discussion of scanners not developed at the Radiation Laboratory."

MATERIALS AND SUBSIDIARY TECHNIQUES

533.56 652
A New Type of Diffusion Pump—E. L. Harrington. (*Rev. Sci. Instr.*, vol. 20, pp. 761–762; November, 1949.) Improvements to the Kerth Hg diffusion pump, reducing noise, operating expenses, and operating temperature, and providing a qualitative measure of the degree of vacuum. The introduction of a Hg seal between the high- and low-vacuum sections makes interrupted operation possible.

535.37 653
Luminescence of Barium-Strontium Oxide—R. E. Aitchison. (*Nature* (London), vol. 164, p. 1088; December 24, 1949.) Well-activated (Ba,Sr) O cathodes gave a pale blue fluorescence under electron bombardment, the total emission spectrum extending from 4,600 Å to 5,400 Å. The intensity of the emitted radiation decreases with increasing oxide temperature and falls rapidly above 700° K. Afterglow is negligible.

535.37 654
The Luminescence Characteristics of Tin-Activated Zinc Sulphide Phosphors—G. F. J. Garlick and D. E. Mason. (*Proc. Phys. Soc.*, vol. 62, pp. 817–822; December 1, 1949.) "It has been found that the inclusion of stannous compounds in relatively large concentrations in the preparation of zinc sulphide phosphors results in an intense red luminescence when excitation is by ultraviolet light of long wavelength (3,650–4,000 Å). Such characteristics as the luminescence spectra, excitation spectra, phosphorescence and thermoluminescence, and the variation of luminescence with temperature have been studied. The hexagonal crystal form of zinc sulphide is essential to the production of efficient phosphors with tin as the activating impurity."

537.228.1:548.0](083.7) 655
Standards on Piezoelectric Crystals, 1949—(PROC. I.R.E., vol. 37, pp. 1378–1395; December, 1949.) Prepared by an IRE committee. Includes (a) definitions of axes for the various crystal systems, (b) specification of crystal-plate orientation, and (c) basic equations, symbols, and units of piezoelectric theory.

538.221 656
On the Conditions for the Occurrence of Ferromagnetism in Metal Compounds—J. H. Gisolf. (*Physica, 's Grav.*, vol. 15, pp. 677–678; September, 1949. In English.) It is necessary though not sufficient, that the lines of communication between the metal atoms which are in exchange interaction form a 3-dimensional network. The ferrites with spinel structure are considered; it appears that only the metal ions in tetrahedron holes can contribute to the ferromagnetism.

538.221 657
Relation between the Thermal Expansion, the Curie Temperature and the Lattice Spacing of Homogeneous Ternary Nickel-Iron Alloys—J. J. Went. (*Physica, 's Grav.*, vol. 15, pp. 703–710; September, 1949. In English.) These quantities were measured for 15 different alloys, all having about 50 per cent Ni and 50 per cent Fe. The change in the expansion anomaly is closely related to the change in Curie temperature. The value of the latter change depends upon the relative positions of Ni and the third alloying element in the periodic system of elements. There is no direct relation between the change in Curie temperature and the lattice spacing.

538.221 658
Ferrogmagnetic Alloys in the Systems Cu-Mn-In and Cu-Mn-Ga—F. A. Hames and D. S. Eppelsheimer. (*Jour. Metals*, formerly *Metals Technol.*, vol. 1, pp. 495–499; August, 1949.) An investigation to determine whether ferromagnetic β-phases exist in these systems analogous to such phases in the systems Cu-Mn-Al and Cu-Mn-Sn. A Cu-Mn-In alloy having an ordered body-centered cubic structure analogous to that of the Heusler alloys is discussed. An alloy $Cu_{1.97}Mn_{1.0}Ga_{10.5}$ variously heat treated is feebly magnetic and has a 2-phase structure. With higher Cu contents, quenched Cu-Mn-Ga alloys are strongly magnetic.

538.221 659
Magnetic Ferrites—C. L. Snyder, E. Albers-Schoenberg, and H. A. Goldsmith. (*Elec. Mfg.*, vol. 44, pp. 86–91; December, 1949.) "Ferramics" consist only of metallic oxides, and have high resistivity and high permeability, but low losses. They can thus be used to reduce the size and weight of high-frequency magnetic apparatus. Properties of typical ferramics are tabulated or shown graphically. See also 3447 of 1948 (Snoek).

538.221 660
Magnetic Ferrites for High-Frequency Uses—F. G. Brockman. (*Elec. Eng.*, vol. 68, pp. 1077–1080; December, 1949.) Discussion of (a) the historical background of research on such materials by the Philips Co. at Eindhoven, Holland, and Irvington-on-Hudson, N. Y., U.S.A., with special attention to the crystallography of the ferrites, (b) characteristics of the materials, (c) applications, and (d) the existence of displacement currents as well as ohmic currents in a core of ferroxcube III. See also 2265 of 1948 (Verwey, Haayman, and Romeyn) and 2387 of 1948 (Rinia et al.).

538.221:621.775.7 661
The Coercive Field of Ferromagnetic Powders—C. Guillaud. (*Compt. Rend. Acad. Sci.* (Paris), vol. 229, pp. 818–819; October 24, 1949.) The variation of coercive field with temperature for a powder consisting of single crystals of Mn_2Sb is discussed.

538.23:621.318.323.2 662
Unsymmetrical Hysteresis Loops in a Nickel-Iron Alloy—J. L. Rothery and An Wang. (*Nature* (London), vol. 164, pp. 1004–1005; December 10, 1949.) A very pronounced asymmetry of the hysteresis loop has been observed in one particular sample of grain-oriented Ni-Fe alloy core when a large dc magnetizing pulse was applied to the core and followed by smaller ac excitation. If the ac excitation is gradually increased until saturation is reached and then reduced, the asymmetry persists except during saturation. Reversal of the magnetizing pulse reverses the loop. The phenomenon persists even if the core is completely disconnected for several days or weeks; the core can therefore be used to store information about the polarity of the last transient magnetizing pulse.

546.431.82 663
Theory of Barium Titanate: Part 1—A. F. Devonshire. (*Phil. Mag.*, vol. 40, pp. 1040–1063; October, 1949.) Dielectric and crystallographic properties are considered. By expanding the free energy as a function of polarization and strain, and making reasonable assumptions about the coefficients, the various crystal transitions can be explained. The dielectric constants, crystal strains, internal energy, and self-polarization are calculated as functions of temperature. Relations are obtained between the coefficients in the free energy and the ionic force constants. These are used to estimate some of the coefficients which are not completely determined by experimental data.

620.197.7 664
Preventing Fungus Damage—E. F. Little. (*Elec. Mfg.*, vol. 44, pp. 89–91, 170; November, 1949.) Fungus attack is to be expected in most climates, but particularly under hot, moist conditions. Materials most liable to attack are those containing organic compounds. Protection is secured by the addition of fungicides harmless to animal life, notably copper-8-quinolinolate and copper naphthanate.

621.315.5/.6 665
Plastics can be Electrical Conductors—(*Elec. Mfg.*, vol. 44, pp. 60–63, 180; November, 1949.) Discussion of Markite materials. For another account see 3443 of 1949.

621.315.59 666
Conductivity in Semiconductors—K. Lark-Horovitz. (*Elec. Eng.*, vol. 68, pp. 1047–1056; December, 1949.) A survey of papers presented at the AIEE summer general meeting.

621.315.59 667
On the Spontaneous Current Fluctuations in Semiconductors—J. H. Gisolf. (*Physica, 's Grav.*, vol. 15, pp. 825–832; September, 1949. In English.) Formulas are derived which indicate that (a) the effective current strength of the fluctuations is proportional to the field strength, (b) at low frequencies the fluctuations are independent of frequency, (c) at high frequencies the effective current strength decreases with increasing frequency, (d) for alternating fields, the fluctuations depend on the difference between the observation frequency and that of the alternating field, and (e) effective current strength is proportional to the square root of the mean life time of the free electrons in the semiconductor.

621.315.59:535.215.1 668
Photoeffects in Semiconductors—(*Elec. Eng.*, vol. 68, pp. 937–942; November, 1949.) Long summary, compiled by J. A. Becker, of 3 papers read at an AIEE symposium on "Electrical Properties of Semiconductors and the Transistor," namely: General Features of Photoconductivity and Photoemission in Semiconductors, by L. Smith; External Photoelectric Effects in Semiconductors, by L. Apker; and Internal Photoeffects in Germanium, by J. N. Shive. For summaries of other papers at this symposium, see 240 of February.

621.318.22 669
Magnetic Saturation Intensities and Curie Temperatures for Some Industrial Permanent Magnet Materials—L. Ward. (*Metallurgia* (Manchester), vol. 41, pp. 3–7; November, 1949.) Magnetic analysis of various steels and alloys indicates that, in alloys of the Alnico type there is a reversible phase up to the Curie point, and that cobalt steels, as industrially heat treated, contain mixtures of austenitic and magnetic-α phases. The apparatus used and the experimental procedure are described.

621.318.22 670
Mechanism of the Coercive Field and of the Remanent Magnetism of Powdered MnBi. Generalization—C. Guillaud. (*Compt. Rend. Acad. Sci.* (Paris), vol. 229, pp. 992–993; November 14, 1949.) The coercive field of ordinary permanent magnets is due to internal strains. Fields obtained with powdered MnBi are of a much higher order of magnitude. It is supposed that in the absence of an inductive field, the elementary magnetic vectors are all parallel, but half of one sense and half of the opposite sense. A sufficient inductive field causes one set of these vectors to rotate so that all are thereafter of the same sense. The effect is more pronounced the smaller the grain size; the cases where one grain includes (a) several elementary Weiss domains, and (b) at most one domain, are considered. This mechanism also exists in certain ferromagnetic substances which belong to the hexagonal system, and also for substances belonging to the cubic system. To obtain the best characteristics in magnets produced from powdered materials, each grain should contain only a single elementary domain and the axes of easy magnetization should be parallel.

669.157.82:621.775.7:537.311.3 671
Electrical Resistivity Measurements on Iron-Silicon Compacts prepared by the Powder Metallurgy Procedure—F. W. Glaser. (*Jour. Metals*, formerly *Metals Technol.*, vol. 1, pp. 475–480; August, 1949.) A study, by means of electrical resistivity measurements, of the progress of diffusion in Fe-Si alloys.

MATHEMATICS

681.142 672
The Binary Quantizer—K. H. Barney. (*Elec. Eng.*, vol. 68, pp. 962–967; November, 1949.) A detailed description is given of apparatus for the continuous conversion of input currents or voltages, varying with time, into discrete binary numbers. When a difference exists between the input voltage and the feedback voltage from the counter circuit, the direction of operation of the counter is controlled by the sign of this difference or error voltage.

681.142 673
An Analogue Computer for the Solution of Linear Simultaneous Equations—R. M. Walker. (Proc. I.R.E., vol. 37, pp. 1467–1473; December, 1949.)

681.142:517.512.2 674
Fourier Coefficient Harmonic Analyzer—S. Charp. (*Elec. Eng.*, vol. 68, p. 1057; December, 1949.) Summary only. A ball-and-roller type of mechanical integrator, specially adapted for determining Fourier coefficients directly. The curve to be analyzed is drawn on graph paper, which is wrapped round a cylinder and inserted into the machine. The curve is tracked manually; counters then give the required coefficients. Each time the curve is scanned another set of coefficients is determined. A range of 100 harmonics can be investigated. The time required for each harmonic is 2–7 minutes, depending on the curve.

681.142:621.318.572 675
Gate-Type Shifting Register—J. H. Knapton and L. D. Stevens. (*Electronics*, vol. 22, pp. 186, 192; December, 1949.) Double-triode trigger circuits are used to store the numbers 1 or 0 of the binary system, and each stage passes its number to a following stage on receipt of a shift pulse. The register operates reliably with 1-μs pulses at 250 kc and numbers have been circulated through six stages at 600 kc.

MEASUREMENTS AND TEST GEAR

621.317.2:620.193 676
A Laboratory for the Study of the Resistance of Materials under Tropical Conditions—A. Nizery and S. Crespi. (*Rev. Gén. Élec.*, vol. 58, pp. 455–468; November, 1949.) A full description of the laboratory equipment at Saint-Cyr is preceded by a study of the actual conditions to be reproduced.

621.317.3:621.396.822 677
The Application of I.F. Noise Sources to the Measurement of Over-All Noise Figure and Conversion Loss in Microwave Receivers—L. A. Moxon. (Proc. I.R.E., vol. 37, pp. 1433–1437; December, 1949.) A method is described of extending noise-diode technique to microwaves, using a frequency changer to produce the required rf test signal from an intermediate-frequency noise source. An experimental procedure has been developed which enables the signal level to be accurately evaluated, subject to such limitations as those of Dicke's reciprocity theorem, which are of little practical significance for the applications so far considered. As in the low-frequency case, measurements are in general independent of receiver bandwidth, there is no stray radiation problem, and the receiver output indicating device may follow any law within wide limits. The necessary components are easy to construct and can be calibrated without the use of additional apparatus. The system is particularly well suited to mixer crystal measurements, since both conversion loss and over-all noise figure can be measured with equal facility, and the latter is readily analyzed in terms of conversion loss and noise ratio. See also 1196 of 1947.

621.317.3(083.74):621.396.931 678
Standards on Railroad and Vehicular Communications: Methods of Testing, 1949—(Proc. I.R.E., vol. 37, pp. 1372–1375; December, 1949.) Prepared by an IRE committee.

621.317.324†:621.396.11 679
The Fresnel Reflection Formula in the Region of Long Waves—E. Roeschen. (*Funk. und Ton.*, vol. 3, pp. 525–528; 1949.) A short description of a method of verification by determining the field distribution beneath a vertical radiator. A 30-m Al mast was mounted on a platform floating on a lake and an earth plate of area 4 m² was arranged symmetrically below the mast. The field distribution at different levels above and below the plate was measured for wavelengths of 217, 437, and 1,450 m. The results are shown graphically.

621.317.335.2†:621.319.4(083.74) 680
Standard Test Capacitors—(*Electronics*, vol. 22, pp. 168, 174; December, 1949.) A T-network of ordinary mica capacitors can provide a very small capacitance (e.g. 0.001 pF) between the extremities of the series elements when the shunt arm is grounded, if the capacitors in the series arms are of only a few picofarads each and the capacitance in the shunt arm is several thousand picofarads. Such networks can be used as low-capacitance standards in the measurement of interelectrode capacitances.

621.317.35:621.3.015.33 681
Analysis of Pulse Shape—G. F. Draffin. (*Proc. I.R.E.* (Australia), vol. 9, pp. 10–15; November, 1948.) A simple graphical method is described for determining the amplitudes of the various harmonics present in a pulse of any waveform. The method is particularly useful for the rapid study of such problems as the effect on pulse shape of frequency-dependent amplification or attenuation.

621.317.373.029.64 682
The Experimental Determination of Phase Characteristics of Circuits for Centimetre Waves—M. Denis and P. Palluel. (*Ann. Radioélec.*, vol. 4, pp. 315–330; October, 1949.) A critical review of the principles, methods, and apparatus used for quantitative measurements of (a) phase displacement between input and output at a fixed frequency; (b) phase variations with frequency, and phase distortion; (c) phase velocity in transmission lines; and (d) phase variation of active quadripoles as a function of certain parameters. The relative advantages and disadvantages of dynamic, reflection, resonance, and transmission methods of measurement are discussed. Illustrations and some details are given of suitable wavemeters and slotted lines.

621.317.43:669.14–41 683
Core-Loss Test for Narrow Silicon-Steel Strip—J. A. Ashworth. (*Bell Sys. Tech. Publ. Monogr.*, B-1667, 8 pp.) Description of a method for measuring the across-grain core loss in silicon-steel strip when the standard ASTM method cannot be applied. The Epstein method is modified by decreasing the lengths of the test windings and test pieces.

621.317.66 684
Measurement of Microwave-Transmission Efficiency—A. L. Cullen. (*Radio Tech. Dig.* (Franç), vol. 3, pp. 345–348; December, 1949.) French version of 3196 of 1949.

621.317.7 685
A New Type of Electrical Instrument—K. A. Pullen. (*Instruments*, vol. 21, pp. 1008–1011; November, 1948.) A double-moving-coil arrangement is used to overcome difficulties caused by vibration, shock, etc. The coils are mounted on opposite ends of the support frames, which carry the pivots at the center. The pointer is an extension of the upper frame. Theory and mechanical details of such instruments are fully discussed. Advantages include high tongue/weight ratio, high sensitivity, low power consumption, and extreme robustness.

621.317.7.089.6 686
Equipment for Instrument Calibration—E. A. Gilbert. (*Elec. Eng.*, vol. 68, pp. 1065–1066; December, 1949.) Description of three self-contained units for the calibration of all types of ac and dc measuring instruments now used, and designed to anticipate future requirements. A power supply at 110–120 v with frequency between 50 and 1,600 cps is required.

621.317.725 687
A New Expanded-Scale A.C. Voltmeter—N. P. Millar. (*Elec. Eng.*, vol. 68, p. 1044; December, 1949.) Summary only. An iron-core saturable reactor is used to energize the moving coil of a standard electrodynamic wattmeter. Accuracy is within about ½ per cent of full-scale rating.

621.317.73.029.63 688
Circular Standing-Wave Detector—(*Radio and Telev. News, Radio-Electronic Eng. Supplement*, vol. 13, pp. 12–13; December, 1949.) A brief general description of the apparatus. For another account see 3198 and 3203 of 1949 (Meinke).

621.317.733 689
Self-Balancing Resistance Bridge—H. F. Rondeau. (*Gen. Elec. Rev.*, vol. 52, pp. 45–46; October, 1949.) A servo system, consisting of an electronic converter and amplifier unit feeding a reversible induction motor, balances the bridge rapidly and automatically. The equipment, which can be switched for manual operation, is recommended for production tests requiring an accuracy of about 1 per cent over the resistance range of 0.01Ω to above 30 kΩ.

621.317.74:621.315.212 690
Maintenance Equipment for Coaxial-Cable Circuits—J. Selz. (*Câbles and Transmission* (Paris), vol. 3, pp. 306–325; October, 1949.) Specifications and description of apparatus constructed in France for making comprehensive line measurements in the range 30 kc to 4 Mc.

621.317.762 691
Loading and Coupling Effects of Standing-Wave Detectors—K. Tomiyasu. (Proc. I.R.E., vol. 37, pp. 1405–1409; December, 1949.) "When measuring impedances on transmission lines, insensitive standing-wave detectors have the effect of yielding lower standing-wave ratios than the true values. Double-hump distribution curves are shown to be the result of very tight coupling of the detector. Detectors that can be represented by a susceptance component may indicate unsymmetrical distribution curves. Sensitive detectors used on transmission lines having low power levels can introduce tight-coupling effects. Conditions are given for a loosely coupled detector."

621.317.79:621.396.615.12 692
Low Frequency Generators—R. A. Raffin-Roanne. (*Radio Prof.* (Paris), vol. 18, pp. 16–20; November, 1949.) Description of two signal generators for testing lf amplifier fidelity. The first provides a sinusoidal output of 500 mw maximum with <3 per cent harmonic distortion, covering 15 to 16,000 cps. The second is an adapter for use with the first to provide a rectangular-wave output. Complete circuit diagrams are given and some aspects of amplifier fidelity are considered.

621.396.933.001.4 693
The Servicing of Airborne Equipment—T. R. W. Bushby. (*Proc. I.R.E.* (Australia), vol. 10, pp. 190–195; July, 1949.) 1948 Australian IRE Convention paper. An outline of the organization of servicing procedure in Australia is given. Servicing requirements and test apparatus are discussed. Instruments for checking transmitter radiation and ignition noise and for the overhaul of relays, microphones, and headphones are described.

OTHER APPLICATIONS OF RADIO AND ELECTRONICS

526.9:621.396.9 694
Geodetic Measurements by Radar—D. J. Halliday. (*Nature* (London), vol. 164, pp. 1005–1006; December 10, 1949.) An aircraft flies in a circular arc at the center of which is a ground radar beacon. The distance of the aircraft from a second beacon is recorded at regular intervals. The geodetic distance between the beacons is calculated from the radius of the arc and the minimum recorded distance from the second beacon, corrections being made for altitude and atmospheric refraction.

531.78:621.3.083.7 695
The Differential Transformer as Applied to Instrumentation—W. D. Macgeorge. (*Science*, vol. 110, pp. 365–368; October 7, 1949.) Basic design of differential transformers is discussed and illustrated by a description and performance details of the "Atcotran" type made by the Automatic Temperature Control Co. Suitable circuits for using these transformers in the measurement of variables such as pressure, flow, and force are also considered; the null-balance type of circuit being especially noted. Practical wiring procedures are given for systems in which the indicating instrument is a considerable distance from the equipment on which measurements are to be made.

535.61–15 696
Some Experimental Demonstrations with Infra-Red Rays—T. Gast. (*Funk. und Ton.*, vol. 3, pp. 529–533; 1949.)

538.71 697
Airborne Magnetometer for Measuring the Earth's Magnetic Vector—E. O. Schonstedt and H. R. Irons. (*Science*, vol. 110, pp. 377–378; October, 1949.) The airborne total field magnetometer, developed during World War II by the Naval Ordnance Laboratory and Bell Telephone Laboratories, has been modified so that the total magnetic field vector is measured instead of the intensity only.

539.16.08 698
Equipment for the Counting of Particles by the Geiger-Müller Method—A. Berthelot. (*Jour. Phys. Radium*, vol. 7, pp. 185–192; July, 1946.) Description of apparatus for laboratory measurements, including scaler circuits, a stabilized hv supply, pulse generator, and a complete unit comprising preamplifier, decade scaler circuit, power stage, counter, power supply, and voltmeter.

539.16.08 699
Glass-Walled Counters with External Cathode—R. Maze. (*Jour. Phys. Radium*, vol. 7, pp. 164–166; June, 1946.) Colloidal graphite is deposited on the outside of a thin-walled tube of ordinary glass with axial wire anode and hydrogen filling. In use as a counter, the inside of the glass becomes charged as uniformly as if it had a conducting surface layer. The arrangement is thus equivalent to the usual type of counter with the cathode earthed through a high resistance in parallel with a capacitance. Owing to the weak secondary effects of glass a production efficiency of 100 per cent can easily be obtained.

539.16.08 700
Ion Mobilities in Geiger-Müller Counters—H. den Hartog and F. A. Muller. (*Physica, 's Grav.*, vol. 15, pp. 789–800; September, 1949. In English.) Formulas and measuring instruments are described for a detailed study of the deionization current in a self-quenching counter. Ion mobility in alcohol is 2.6 cm/sec per V/cm, in argon 7.1 cm/sec per V/cm, both at 100 mm Hg pressure. These results supersede earlier measurements by van Gemert and the authors, noted in 1139 of 1949.

539.16.08 701
Spurious Counts in Geiger Counters and the Pretreatment of the Electrodes—J. D. Louw and S. M. Naudé. (*Phys. Rev.*, vol. 76, pp. 571–572; August 15, 1949.)

539.16.08 702
On the Temperature Dependence of Counter Characteristics in Self-Quenching G-M Counters—O. Parkash. (*Phys. Rev.*, vol. 76, pp. 568–569; August 15, 1949.)

551.508.1:621.317.083.7 703
Range-Adjusting Radiosonde Recorder—G. E. Beggs, Jr. (*Elec. Eng.*, vol. 68, p. 990; November, 1949.) Summary of AIEE paper. Range-adjustment and calibration are performed automatically. A block diagram of the complete system is included.

621.316.718 704
Basic Control Requirements of D.C. Adjustable-Voltage Drives—E. E. Moyer and M. E. Cummings. (*Elec. Mfg.*, vol. 44, pp. 64–70; November, 1949.) Discussion of the field control sequences for starting, accelerating, running, retarding, reversing, and stopping the motor unit of a dc adjustable-voltage drive of the Ward-Leonard type. The necessary design information is given mainly in a comprehensive series of scaled diagrams, with brief notes.

621.316.726:[621.365.55†+615.84 705

Industrial Oscillator Frequency Control—J. W. Lower. (*Electronics*, vol. 22, pp. 84–86; December, 1949.) Describes an automatic-frequency-control system for diathermy or dielectric-heating power oscillators. The oscillator frequency is sampled 200 times per sec and compared with a crystal-controlled reference frequency. The resulting error signal is applied to a servo system operating a 2-phase induction motor which adjusts the reactive tuning element of the oscillator, whose frequency is this kept within 0.01 per cent of the 27-Mc standard.

621.317.39:534.08 706

A New Method of Vibration Measurement for the Frequency Range 20 to 20,000 c/s—F. Massa. (*Instruments*, vol. 21, pp. 1012–1014; November, 1948.) An accelerometer unit is designed so that its electromechanical system has a single degree of freedom and its resonance frequency is above 20 kc. The unit consists of a system of ADP crystal plates mounted within a cylindrical stainless-steel housing 1 in. in diameter and 2 in. long. A stress is imparted along the piezoelectric axis of the plates in proportion to the component of mechanical vibration in the direction of the cylinder axis. Typical response curves are shown and discussed.

621.365.54† 707

Production Economies realized by Proper Use of Induction Heating—J. A. Evans. (*Materials and Methods*, vol. 30, pp. 57–60; November, 1949.)

621.38.001.8 708

Electronics Symposium, 1949—(*Engineer* (London), vol. 188, p. 525; November 4, 1949.) Brief notice of the papers presented and the apparatus exhibited at a symposium on instruments in research and industry, held in London, November 2–4, 1949.

621.38.001.8 709

Electronic Aids to Industry—(*Jour. Brit. I.R.E.*, vol. 9, pp. 446–464; December, 1949.) A survey prepared by the Technical Committee of the British I.R.E. Applications are grouped in 33 sections, each with a bibliography which, though not exhaustive, may serve as a guide to more detailed technical information.

621.38.001.8:543/545 710

Electronic Instrumentation for Chemical Laboratories—F. Gutmann. (*Proc. I.R.E.* (Australia), vol. 10, pp. 241–254; September, 1949. Bibliography, pp. 254–256.) Paper presented at the Australian I.R.E. convention, Sydney, 1948. A comprehensive survey, with many diagrams of the principles of various analyzing instruments, including pH meters and the associated current amplifiers, colorimeters using photoelectric cells, polarographs for the analysis of electrolytes by measurement of the current/voltage curve, gas analyzers, titration potentiometers, electrolytic conductance bridges, dielectric-constant and dielectric-loss measuring equipment for radio frequencies, moisture meters, supersonic equipment, an ionization gauge, and an electronic balance.

PROPAGATION OF WAVES

061.3:551.510.535:538.566 711

The Conference on Ionospheric Research—(*Jour. Geophys. Res.*, vol. 54, pp. 281–294; September, 1949.) Summaries of symposia and abstracts of papers presented at the conference held at Pennsylvania State College under joint sponsorship of that College and of the Geophysical Research Directorate, U.S.A.F., June 27–29, 1949. Selected papers are noted below, in this section, or in the Geophysical and Extraterrestrial Phenomena section.

538.56 712

General Expression of Huyghens' Principle for Electromagnetic Waves in an Imperfectly Transparent Medium—J. Brodin. (*Compt. Rend. Acad. Sci.* (Paris), vol. 229, pp. 1064–1066; November 21, 1949.) Extension of 523 above to the case of em waves. The layers involved in this case consist respectively of electric and magnetic dipoles.

538.566 713

On the Electromagnetic Surface Wave of Sommerfeld—T. Kahan and G. Eckart. (*Phys. Rev.*, vol. 76, pp. 406–410; August 1, 1949.) See 2892 of 1949.

538.566.3:551.510.535 714

Application of the Magneto-Ionic Theory to Radio Waves Incident Obliquely upon a Horizontally-Stratified Ionosphere—H. G. Booker. (*Jour. Geophys. Res.*, vol. 54, pp. 243–274; September, 1949.) Pennsylvania State College Conference paper. "A study is made of the propagation of wave-packets incident obliquely upon a slowly varying plane-stratified ionosphere, allowing for the full effect of the earth's magnetic field. Propagation of a magneto ionic component is described in terms of the vertical component q of the phase-propagation vector, so as to avoid using a refractive index which depends in a complicated way on an unknown angle of refraction. The fundamental formula of the theory is an algebraic quartic equation for q, the coefficients in which depend on electron-density N, wave-frequency, direction of earth's magnetic field, the direction of incidence upon the ionosphere. The four roots of the quartic for q correspond to the upgoing/downcoming ordinary/extraordinary magneto-ionic components.

"It is shown that, to plot the four roots of q as a function of N for fixed values of the other parameters, it is easier to restate the fundamental formula as a cubic equation for N as a function of q. Using this cubic equation, simple limiting curves between which the actual curves necessarily lie are deduced, thereby facilitating plotting in a particular case. Methods for mass-production of such propagation-curves are devised but not applied on a large scale.

"Formulas for attenuation, lateral deviation, horizontal range, and equivalent paths of magneto-ionically split wave-packets are derived and illustrated graphically. The amount to which a wave-packet can be permanently deviated out of its plane of incidence by the earth's magnetic field can be extremely large, but probably not in cases of practical importance in commercial radio communication."

621.396.11 715

The Reflection Coefficient of a Linearly Graded Layer—G. Millington. (*Marconi Rev.*, vol. 12, pp. 140–151; October–December, 1949.) A study of the reflection of a horizontally polarized plane wave incident obliquely on a layer in which there is a linear variation of dielectric constant from a constant value on one side of the layer to another constant value on the other side of the layer. The curves given have particular application to the propagation of uhf radio waves in the troposphere, and should be a useful contribution to the understanding of uhf long-distance transmission.

The curves refer only to horizontal polarization, but when the change in refractive index is very small and the wave is at nearly grazing incidence, the reflection coefficients for vertical and for horizontal polarization are approximately equal numerically, though their analytical forms are different. Under these strictly limited conditions, the curves may also give the numerical value of the reflection coefficient for vertical polarization.

621.396.11:523.72 716

Observations of the Propagation of Broadcasting Waves, $\lambda = 1250$ m, during the Occurrence of Mögel-Dellinger Effects—E. A. Lauter. (*Z. Met.*, vol. 3, pp. 204–206; July, 1949.) D-layer reflection effects, scattering, and absorption effects for 1250-m waves are discussed in relation to the occurrence of outbursts of ultraviolet emission from the sun and consequent fading of broadcasting signals. The Mogel-Dellinger effect does not appear to have been observed hitherto for such long waves. Its occurrence may give new insight into the ionization of the middle stratosphere.

621.396.11:535.31:551.510.535 717

Geometrical Optics of the Ionosphere—K. Rawer. (*Rev. Sci.* (Paris), vol. 86, pp. 585–600; September and October, 1948.) The dependence of field strength upon path length is considered, and a solution is obtained involving the diameter of the ray in the vertical plane containing its path. Calculations are made for the cases of flat and curved earth, and thin and thick ionospheric layers. Diameter/distance curves are plotted. Results obtained for single and multiple reflections show three focal points, (a) at the edge of the silent zone, (b) for the horizontal ray, and (c) for the antipodal point. Approximations for the case of a parabolic layer are considered and discrepancies between these and the results of Försterling and Lassen (1932 Abstracts, pp. 87 and 217) and of Appleton and Beynon (3290 of 1949) are noted. The application of the curves finally obtained to propagation problems is briefly considered.

621.396.11:551.510.535 718

Ray Paths of Radio Waves in the Ionosphere—H. Poeverlein. (*Z. Angew. Phys.*, vol. 1, pp. 517–525; October, 1949.) Detailed discussion of the theoretical bases for the graphical construction of ray paths. Several graphical representations of the dependence of the refractive index on the direction of the wave normal are given and discussed.

621.396.11:551.510.535 719

Some Problems of Wave-Diffraction in the Ionosphere—J. A. Ratcliffe. (*Jour. Geophys. Res.*, vol. 54, p. 288; September, 1949.) Summary of Pennsylvania State College Conference paper. "Simultaneous observations of radio 'fading' at two points force us to the conclusion that radiowaves are returned from the ionosphere by a process of diffractive reflection as if from a rough surface. The diffraction effects produced by a simple model of this kind are considered and are related to well-known phenomena of optical diffraction. It is shown that the methods of calculation are similar to those employed in the analysis of random fluctuations such as occur with radio 'noise.' The fading is shown to be produced by movements of the random irregularities in the ionosphere and is related to their turbulent or regular motions. It is shown how winds in the ionosphere can be measured. Analogies are made with some well-known optical phenomena."

621.396.11:551.510.535 720

Oblique Incidence Propagation Work of the Central Radio Propagation Laboratory—R. Silberstein. (*Jour. Geophys. Res.*, vol. 54, p. 288; September, 1949.) Summary of Pennsylvania State College Conference paper. Discussion of experiments, begun in 1947, using a 13.7-Mc transmitter capable of an output of several hundred kilowatts. Three methods were used to determine the source of back-scatter;

the results indicated that ground-scatter usually predominated over scatter from the E layer. An examination of A-scope photographs confirmed the existence of many of the predicted modes of propagation.

621.396.11:551.510.535 721
The Interpretation of Long Scatter Echo Patterns—A. M. Peterson. (*Jour. Geophys. Res.*, vol. 54, p. 284; September, 1949.) Summary of Pennsylvania State College Conference paper. The mechanism of ground scatter is analyzed. It is shown that "angle" focusing and "time-delay" focusing produce characteristic patterns on pulse-echo equipment. It is deduced that E-region ionization contributes relatively little to long scatter.

621.396.11:551.510.535 722
Pulse Transmission over Long Distances—J. A. Pierce. (*Jour. Geophys. Res.*, vol. 54, pp. 282–283; September, 1949.) Summary of Pennsylvania State College Conference paper. The two methods used for recording fixed-frequency pulse signals received from a distant transmitter are discussed. These are (a) the use of stable oscillators to control the recurrence period; and (b) the use of a servomechanism to synchronize the controlling oscillator with the received signal. Examples are shown of the records obtained with the synchronizer at frequencies of 9.1 and 12.9 Mc, chosen to exhibit the effects of the Pedersen ray. The effects of seasonal changes between July, 1948, and June, 1949, on the propagation of a 17-Mc signal over a 6,000-km transatlantic path are studied, and comparisons made with C.R.P.L. predictions.

621.396.11:551.510.535 723
Effect of the D-Ionospheric Layer on Very Low Frequency Radio Waves—W. P. Pfister. (*Jour. Geophys. Res.*, vol. 54, p. 286; September, 1949.) Summary of Pennsylvania State College Conference paper. The D layer considered is a normal Chapman layer at a height of about 60 km. In long-distance propagation, maximum absorption is observed at 45 kc, and the calculated ion concentration is of the order of $100/\text{cm}^3\text{sec}$. Reflection coefficients, transmission values, and virtual heights are also calculated. Different conceivable forms of ion distribution are considered.

621.396.11:551.510.535 724
The Propagation of Long and Very-Long Waves—J. A. Ratcliffe. (*Jour. Geophys. Res.*, vol. 54, pp. 281–282; September, 1949.) Summary of Pennsylvania State College Conference paper. An account of the measurements which have been made in England since the war, to investigate reflection from the ionosphere at steep incidence. Results are described of investigations at frequencies between 16 kc, for which the daytime downcoming wave is strong, and 100 kc, for which the reflected wave is weak.

The variations in the phase of the reflected wave are recorded for transmissions over different distances; the results provide information about changes in the equivalent height of reflection. An account is given of deductions made from the normal diurnal and annual variations.

A sudden phase anomaly often accompanies a sudden ionospheric disturbance and is observable throughout the disturbance because the amplitude of the very long wave is not seriously diminished by the disturbance. The importance of these anomalies for solar and ionospheric theories is discussed.

Attempts are being made to relate propagation at oblique incidence to propagation at more vertical incidence, both by plotting the ground interference pattern in an aircraft and by making detailed measurements at a point distant 500 km from the transmitter.

621.396.11:551.510.535 725
Sporadic Ionization at High Latitudes—J. H. Meek. (*Jour. Geophys. Res.*, vol. 54, pp. 284–285; September, 1949). Summary of Pennsylvania State College Conference paper. Discussion of the variations in the (h', f) trace produced by different types of sporadic ionization recorded in northern Canada. Estimates of the speed of motion of sporadic ionized clouds range from 400 km/hr to 1,200 km/hr for virtual heights from 100 km to 300 km.

621.396.11:551.510.535 726
Summary of Symposia [at the Pennsylvania State College Conference]—Waynick. (*See* 637.)

621.396.11:621.317.324† 727
The Fresnel Reflection Formula in the Region of Long Waves—Roeschen. (*See* 679).

621.396.11:551.594.5 728
Sky-Wave Observations (λ=1250 m) during Displays of the Northern Lights in 1947—E. Lauter and K. Sprenger. (*Z. Met.*, vol. 3, pp. 193–198; July, 1949.) Numerous northern-light observations at German stations on 40 nights during 1947 are correlated with observations at Warnemunde of 1250-m waves reflected from the E-layer. The relation of sky-wave absorption to sunspot relative numbers and to geomagnetic quantities is considered both for evenings with northern-light displays and for those with abnormal E-layer effects.

621.396.11.029.6 729
V.H.F. and U.H.F. Propagation within the Optical Range—M. W. Gough. (*Marconi Rev.*, vol. 12, pp. 121–139; October–December, 1949.) The mechanism of vhf and uhf propagation can be explained in terms of five major factors, namely (a) atmospheric refraction, (b) ionospheric reflection, (c) tropospheric reflection, (d) diffraction, and (e) ground reflection. (e) is the dominant factor in propagation within the optical range, and it is with this aspect of the problem that this article is concerned.

From the ray concept of propagation, a technique has been evolved using simple microwave field strength measurements to forecast the behavior of vhf and uhf transmissions over a specific optical path. In particular the method predicts, without further measurement, the best height for the receiving antenna on any frequency in the vhf or uhf band.

The process is based on the assumption that ground reflection is confined to a point. This assumption becomes increasingly invalid with increasing wavelength and may lead to errors. However, these can be corrected to a large extent by invoking Fresnel's zone theory, which defines what region of the path is involved in reflection. Furthermore, by examining the ground irregularities in this region the reflecting power of the ground can be assessed.

This article develops the theory of the microwave survey technique and describes and interprets a survey made over a test path, from which the behavior of specific longer waves is predicted. It concludes with a description of confirmatory experiments made over the same path which verify the predictions.

The "calibration" of optical paths by the use of microwaves eliminates the necessity for tests on operational wavelengths, and coupled with the lightness and compactness of microwave equipment, saves experimental labor, particularly if the path is to carry transmissions on more than one wavelength.

621.396.81:523.78 730
Field-Strength Observations Made during the Total Eclipse of the Sun—J. Gross. (Proc. I.R.E., vol. 37, p. 1447; December, 1949.) Curves are given showing the estimated signal strength and readability of WWV sw signals received at Eastleigh aerodrome, Nairobi, on November 1, 1948. The transmission path was approximately the same as that of the eclipse. Signals disappeared completely during the totality period and returned to normal by the time the sun was completely unobscured. Signals were of normal strength both on the day before and the day after the eclipse.

621.396.81:621.396.67.029.64 731
The Effect of Antenna Size and Height Above Ground on Pointing for Maximum Signal—A. H. LaGrone and A. W. Straiton. (Proc. I.R.E., vol. 37, pp. 1438–1442; December, 1949.) An account of investigations of 3.2-cm transmissions over a 27-mile desert path in Arizona. The effect of antenna size and height above ground on the angle of arrival, as indicated by pointing the antenna for maximum signal, is shown in tables and curves for three measured fields. A comparison is also made of the response of the antennas for various angles of tilt in these fields, and their response in an assumed field made up of two plane-wave components.

621.396.812 732
Ground-Wave Field-Strength Calculation—H. L. Kirke. (Proc. I.R.E., vol. 37, p. 1446; December, 1949.) Comment by G. Millington on 2304 of 1949 and author's reply.

RECEPTION

621.396.621 733
Reflex Receiver with Feedback and A.V.C.—E. G. Beard. (*Philips Tech. Commun.* (Australia), No. 4, pp. 9–14; 1949.)

621.396.621:621.396.619.13 734
Sky-Wave F.M. Receiver—L. B. Arguimbau and J. Granlund. (*Electronics*, vol. 22, pp. 101–103; December, 1949.) Early experiments showed that reception in the presence of multipath signals was much inferior for FM than for AM. When signal and interference (multi-path or other) are of nearly equal amplitude, the limiter must have a uniform response over a very wide band. Thus when two signals differ in amplitude by 5 per cent and in frequency by 150 kc the resultant will sweep through 6 Mc, and the limiter must pass all these frequencies equally so as not to introduce AM. A brief description of circuits and laboratory tests of a receiver is given and it is suggested that a transatlantic FM high-fidelity link should be possible if a channel of width 150 kc could be spared in the sw band.

621.396.623 735
A De Luxe Receiver with Very High Musical Fidelity: Le Jubilé—J. Rousseau. (*TSF Pour Tous*, vol. 25, pp. 398–404; December, 1949.) An illustrated description of the circuit features of a 33-tube broadcast receiver built by M. Laugier and incorporating various design recommendations which have appeared in the journal in recent years. References to these articles are made on a complete circuit diagram. The receiver has six wavebands and uses three separate amplifier stages for high, medium, and low audio frequencies, and an expansion circuit for contrasts.

621.396.822 736
Note on Transit-Time Deterioration—A. van der Ziel. (Proc. I.R.E., vol. 37, p. 1447; December, 1949.) A simple derivation of some formulas recently published by MacDonald (2408 of 1949). See also 1890 of 1948 (Strutt and van der Ziel).

621.396.822:621.317.3 737
The Application of I.F. Noise Sources to the Measurement of Over-All Noise Figure and

Conversion Loss in Microwave Receivers—Moxon. (*See* 677.)

621.396.621 738
Les Récepteurs de Radiodiffusion (Broadcasting Receivers) [Book Review]—Y. Angel. Publishers: Eyrolles, 244 pp. (*Radio Tech. Dig.* (Franç), vol. 3, p. 375; December, 1949.)

STATIONS AND COMMUNICATION SYSTEMS

621.395+621.397]:621.315.212 739
Progress in Coaxial Telephone and Television Systems—L. G. Abraham. (*Bell Sys. Tech. Publ. Monogr.* B-1630, 8 pp.; *Trans. AIEE*, vol. 67, pp. 1520–1527; 1948.) A general description of the Bell Telephone L1 system, which provides either 600 telephone circuits or a 2-way television circuit with a bandwidth of 2.8 Mc, with details of the coaxial cables used and their associated equipment.

621.395.635:621.395.44:621.396.931 740
Vibrating Reed Selective Signaling System for Mobile Telephone Use—H. M. Pruden and D. F. Hoth. (*Bell Sys. Tech. Publ. Monogr.*, B-1663, 5 pp.; *Trans. AIEE*, vol. 68, pp. 387–391; 1949.) A means of calling a particular car in a group tuned to a common carrier frequency. The transmitter at the fixed station can transmit any combination of four af tones from the 32 available, 10,000 combinations being possible. Each car is equipped with a set of four vibrating-reed selectors (756 below) tuned to selected tones, the combination being different for each car. The operation and advantages of the system are discussed.

621.396.1:621.396.931 741
Radio Communications Services: Part 2—(*FM-TV*, vol. 9, pp. 18–21, 45; July, 1949.) Continuation of 2907 of 1949.

621.396.1:621.396.931 742
New Frequency Assignments for Mobile-Radio Systems—G. H. Underhill. (*Elec. Eng.*, vol. 68, pp. 951–955; November, 1949.) Description of the method by which a new operating frequency will be selected for each of 500 mobile-radio systems.

621.396.619.13 743
On the Question of the Applicability of Single-Sideband Methods for Frequency-Modulation Transmissions—A. Lutsch. (*Fernmeldetech. Z.*, vol. 2, pp. 347–351; November, 1949.) A theoretical treatment of the subject shows that no simple demodulation process can be applied. Investigation of the AM which occurs in single-sideband systems indicates that the phase swing is limited to <1.7 radians, so that only narrow-band modulation is possible. Formulas are given for determining the behavior of the demodulated low-frequency curves, and distortion is discussed. From these considerations, single-sideband FM appears to be impracticable for communication purposes.

621.396.619.13:621.396.712:534.86 744
A Demonstration of Experimental F.M. Broadcast Transmitting and Receiving Equipment—Honnor. (*See* 535.)

621.396.65.029.63 745
A Wide-Band V.H.F. Radio-Relay System—W. S. McGuire. (*Proc. I.R.E.* (Australia), vol. 10, pp. 160–165; June, 1949.) Paper presented at the Australian I.R.E. convention, Sydney, 1948. The link operates in the frequency range 152–165 Mc, the frequency deviation being ± 30 kc. Frequency response is constant to within ± 1 db from 50 cps to 17 kc. Terminal and repeater equipment are described, with performance figures for an experimental 22-mile link.

621.396.712+621.396.97 746
High-Frequency Broadcasting in Australia—N. S. Smith. (*Proc. I.R.E.* (Australia), vol. 9, pp. 4–20; October, 1948.) Paper presented at the Australian I.R.E. Convention, November, 1948, and giving an historical outline of the development of broadcasting in the frequency band 3–30 Mc. The transmission characteristics of the ionosphere, as they affect this band, are summarized. "Internal" and "external" services are dealt with in two main sections and brief technical summaries are included of the transmitters, the power output of which ranges from 1 to 100 kW. Descriptions are given of antenna arrays and switching arrangements.

621.396.72:621.3.018.4(083.74) 747
Experimental Standard-Frequency [3-kW] Transmitting Station, WWVH—G. H. Lester. (*Communications*, vol. 29, pp. 20–23, 33; September, 1949.) See also 1982 of 1949.

621.396.931:621.317.3(083.74) 748
Standards on Railroad and Vehicular Communications: Methods of Testing, 1949—(Proc. I.R.E., vol. 37, pp. 1372–1375; December, 1949.) Prepared by an IRE committee.

621.396.931:621.396.619.13 749
South Australian Police F.M. Network—R. W. Goss. (*Communications*, vol. 29, pp. 14–16; September, 1949.) General description of the 72.5-Mc system, which comprises a 250-w transmitter located in Adelaide, a 25-w remote station 1,250 ft. above sea level, and 10-w mobile units. Points within 25–30 miles of the 250-w transmitter are covered.

621.396.931:621.396.619.13 750
Mobile F.M. Communications Equipment for Australian Conditions—R. A. Ratcliffe and R. S. Zucker. (*Proc. I.R.E.* (Australia), vol. 10, pp. 101–113; April, 1949. Correction, vol. 10, p. 159; June, 1949.) Paper presented at the Australian I.R.E. convention, Sydney, 1948. Examples of performance specifications for mobile FM vhf equipment, issued by various public bodies in Australia, and also for typical American installations are tabulated and discussed. A standard performance specification for Australian equipment is proposed. A description is given, with photographs and circuit diagrams, of mobile transmitter and receiver units designed to meet the requirements of the proposed specification.

621.396.931:621.396.619.13 751
V.H.F. Mobile Communication Systems—A. J. Campbell. (*Proc. I.R.E.* (Australia), vol. 10, pp. 73–82; March, 1949.) Paper presented at the Australian I.R.E. convention, Sydney, 1948. The main factors which have encouraged the development of such systems are reviewed. A detailed description is given of a standardized range of FM equipment designed to provide reliable service over an area of at least 20-miles radius around a central station. Carrier frequencies in the bands 70–80 Mc and 152–166 Mc are used, with crystal control of the transmitter frequency. The double-superheterodyne receivers derive both local-oscillator frequencies from appropriate points in a crystal-driven multivibrator chain, the crystals vibrating in the third harmonic mode and thus providing initial high frequencies which greatly simplify design. Various types of antennas are available. Two selective-calling systems are mentioned: (a) a 2-tone system for a maximum of 33 mobile units, in which mechanically resonant reed selectors are fitted; and (b) a digit system similar in principle to that of the automatic telephone. This has a much greater capacity than the 2-tone system. With a 2-digit code, about 80 mobile units can be called.

621.396.933 752
The Modern Civil Aircraft Radio Station—S. C. Wallace. (*Marconi Rev.*, vol. 12, pp. 152–156; October–December, 1949.) The methods of installing radio instruments in aircraft are reviewed. The general trend towards standardization has now developed into the "standard racking scheme." This is described and its use illustrated.

SUBSIDIARY APPARATUS

621.526:623.451 753
German Missile Accelerometers—T. M. Moore. (*Elec. Eng.*, vol. 68, pp. 996–999; November, 1949.) Control of steering and fuel cut-off in German rocket missiles was effected by various methods based on the measurement and integration of acceleration. Single integration systems used gyroscope precession and electro-deposition. A circuit for double integration by electro-deposition methods is described. A system for lateral control, using an electrically maintained moving-coil vibrator, is also described; by triple integration of lateral acceleration the missile was made to return to its course in spite of side winds.

621.314.5:621–526 754
An Electronic D.C. to A.C. Converter for Use in Servo Systems—E. E. St. John. (Proc. I.R.E., vol. 37, pp. 1474–1478; December, 1949.)

621.314.632 755
The Easy-Flow Characteristics of Copper Oxide Rectifiers—F. Rose and E. Spenke. (*Z. Phys.*, vol. 126, pp. 632–641; August 30, 1949.) The present diffusion theory of dry rectifiers gives the dc characteristics only qualitatively. An improvement in measurement technique and a more exact interpretation of the theory shows that, for Cu_2O rectifiers, large portions of the easy-flow characteristic are given quantitatively by the theory. The existence of the chemical barrier layer is confirmed. See also 826 of 1942 (Schmidt).

621.395.635 756
Vibrating Reed Selectors for Mobile Radio Systems—A. C. Keller and L. G. Bostwick. (*Bell Sys. Tech. Publ. Monogr.*, B-1662, 4 pp.; *Trans. AIEE*, vol. 68, pp. 383–386; 1949.) The vibrating reeds are attached to a metal block to form a small tuning fork. A pole-piece attached to a small magnet is arranged centrally between the tines and an actuating coil surrounds both tines and pole-piece. When the coil is energized with the correct frequency and voltage, the tines vibrate, thus causing a contact to close during a fraction of each cycle of vibration. Another type, without contacts, can be used to provide sharply selective filters. Performance data, graphs, and photographs are included.

621.396.622 757
Theoretical and Experimental Study of Detection by Silicon Crystals—Lapostolle. (*See* 788.)

621.396.68:621.397.62 758
Power Supplies for Home Television Receivers—V. Wouk. (*Elec. Eng.*, vol. 68, pp. 1061–1065; December, 1949.) Discussion, with circuit diagrams, of various methods of supplying (a) low-voltage B+ and bias power, and (b) high-voltage power for the cathode-ray tube.

778.3:621.317.755 759
Techniques in High-Speed Cathode-Ray Oscillography—C. Berkeley and H. P. Mansberg. (*Jour. Soc. Mot. Pic. Eng.*, vol. 53, pp. 549–578; November, 1949.) Photographic technique for recording cathode-ray oscillo-

graph traces of (a) recurrent, (b) transient, and (c) drifting phenomena is discussed.

TELEVISION AND PHOTOTELEGRAPHY

621.397.335 760

A Television Synchronising-Signal Generator—J. E. Benson, H. J. Oyston, and B. R. Johnson. (*Proc. I.R.E.* (Australia), vol. 10, pp. 128–139; May, 1949.) Paper presented at the Australian I.R.E. convention, Sydney, 1948. The synchronizing-signal waveforms of the British and American television systems are described, and the technical requirements of the generating equipment are indicated. An outline is given of some typical circuit techniques used in synchronizing generators, and an experimental 525-line 25-frame synchronizing-signal generator unit is described which uses equalizing pulses and is suitable for negative modulation.

621.397.5 761

Distant Electric Vision—J. D. McGee. (*Proc. I.R.E.* (Australia), vol. 10, pp. 211–223; August, 1949.) 1948 Australian I.R.E. Convention lecture. A historical review of television, with special reference to the development of the emitron, super-emitron and C.P.S. emitron, and discussion of their relative merits. (*Note.* This lecture was recorded in England on magnetic tape and reproduced, with slides, in Sydney. The tape, slides and original manuscript were sent from England by air mail.)

621.397.5 762

Dr. Lee de Forest's Color Television System—(*Tele-Tech*, vol. 8, pp. 41–42; November, 1949.) Tricolor filters, made up of hexagonal elements of the three primary colors, are made to oscillate synchronously before the camera and the reproducing cathode-ray tube, so that every element of the transmitted picture is scanned by each of the primary colors every twentieth of a second.

621.397.5 763

New Directions in Color Television—D. G. F. (*Electronics*, vol. 22, pp. 66–71; December, 1949.) Comparison of the field-sequential, line-sequential, and dot-sequential methods of transmission. Principles of the C.B.S., C.T.I., and R.C.A. systems are discussed.

621.397.5:535.88 764

An Experimental Large-Screen Television Projector—P. Mandel. (Proc. I.R.E., vol. 37, pp. 1462–1467; December, 1949.) Description of equipment for projection on a special screen of the directional type. The screen, of dimensions 3 m×2.25 m, is an assembly of about 15,000 elementary screens, each consisting of 200 very small spherical mirrors stamped in a highly polished Al sheet. See also 2941 of 1948.

621.397.61:621.396.619.23 765

Mid-Level Modulation for TV Transmitters—N. H. Young. (*Communications*, vol. 29, pp. 10–11; September, 1949.) Modulation is applied to the grid of the penultimate rf amplifier and the vestigial sideband characteristic is provided by a filter between the transmitter and the antenna. The size and cost of the modulator system are thus reduced.

621.397.62 766

Influence of the Choice of a Television Standard on the Construction of Receivers—M. Chauvierre. (*Radio Franç.*, No. 11, pp. 7–17; November, 1949.) Discussion with particular reference to receiver cost and quality of reception. Part 1 deals with the effect of synchronization and modulation methods on image stability. In part 2 the choice of the line standard is considered with respect to receiver cost. Part 3 presents the results of comparisons of the definition theoretically possible with that actually observed for about 1,000 receivers, 600 in the U.S.A., 100 in England, and 300 in France. The majority of the receivers gave definition much inferior to that corresponding to the quality of the transmission. From the point of view of economical receiver construction, positive video modulation with AM for the sound channel is preferable. The line standard should be in the range from about 400 to about 600 lines. For very high definition in de-luxe receivers and for large-screen projection a standard of over 1,000 lines appears indispensable.

621.397.62 767

Study of a Sound Receiver for Television—H. Gilloux. (*Radio Prof.* (Paris), vol. 18, pp. 14–16; November, 1949.) The miniature receiver described, working on 42 Mc, gave satisfactory results at distances up to 100 km from a standard transmitter. It uses rimlock tubes and has a normal sensitivity of 200 μv, using an EF42 high-frequency stage with an input impedance of 75Ω. Circuit details and constructional features are noted.

621.397.62 768

The Video-Frequency Stage—R. Gondry. (*Télév. Franç.*, No. 53, pp. 6–9; November, 1949.

621.397.62:621.318.4 769

Coils for Television Receivers—F. Juster. (*Télév. Franç.*, No. 53, pp. 15–18, 24; November, 1949.) Graphical methods for designing high-frequency, intermediate-frequency, and video-frequency coils with maximum Q.

621.397.62:621.396.615.17]:621.385.2 770

The Efficiency Diode in Television Line Time Bases—Coxall. (*See* 782.)

621.397.82:621.326 771

TV Interference from Incandescent Lamps—D. G. F. (*Electronics*, vol. 22, pp. 132, 148; December, 1949.) Intermittent contact of a lamp filament with its supports may produce short rf pulses in the 50–100-Mc region, which repeat at power-line frequency.

621.397.5 772

Basic Television [Book Review]—B. Grob. Publishers: McGraw-Hill, New York, 1949, 596 pp., $5.00. (*Electronics*, vol. 22, pp. 232, 234; December, 1949.) The author "has managed to present the entire field of television in a completely understandable and logical way which should appeal to the technician who is sincerely interested in what really goes on behind the picture tube."

TRANSMISSION

621.317.726 773

Simplified Frequency Stabilization—O. A. Tyson. (Proc. I.R.E., vol. 37, p. 1445; December, 1949.) About 1 per cent of the output of a klystron is diverted by a directional coupler to a frequency discriminator comprising an unmatched hybrid junction, a phase changer, and a resonant cavity. The phase changer is adjusted to deliver equal modulated power to the detectors terminating the E and H arms of the hybrid when the cavity is detuned and the automatic-frequency-control switch is "off." The cavity is then tuned to resonance, which again equalizes the power in the E and H arms, and the automatic-frequency-control switch is turned to "on." Any subsequent frequency drift unbalances the system and the amplified and rectified detector outputs can be used to control the modulator tube and hence the amplitude of the square-wave output, which is applied to the steady-state klystron reflector voltage by derivative coupling, with the result that the oscillation frequency is stabilized. The scheme, with slight modification, can be made to work either with cw or AM output. Stabilization to within about 1 part in 10^5 is obtained.

621.396.61 774

Citizens' Band Transmitter—A. R. Koch. (*Electronics*, vol. 22, pp. 118, 132; December, 1949.) Describes the construction of a small transmitter giving an output of 7w at 450 Mc. The tripler and power-amplifier stages use capacitor-tuned parallel-plate resonant lines with lighthouse tubes. For other articles on Citizens' Radio see 3482 of 1949 (Lurie) and back references.

621.396.61:621.396.97 775

Co-ordinated Design of A.M. Broadcast Transmitters for a Range of Power Output—P. R. Hellyar. (*Proc. I.R.E.* (Australia), vol. 10, pp. 181–189; July, 1949.) 1948 Australian I.R.E. Convention paper. A basic design of mf (540–1,600 kc) AM broadcast transmitters, for the output range 200 w-60 kw, is considered with particular reference to Australian requirements. Standardization of components and methods gives advantages in both design and manufacture without sacrifice of performance or appearance. Details of several standardized transmitters are included.

621.396.61.029.56/.58 776

S.F.R. 10-kW Short Wave Transmitter—H. Grumel. (*Ann. Radioélec.*, vol. 4, pp. 344–357; October, 1949.) An illustrated description of a standardized communications transmitter designed for telegraphy and telephony operation in any climate on heavy-traffic commercial channels. Separate hf units provide for simultaneous operation in three bands which together cover the frequency range 2.5–23 Mc. Frequencies are crystal controlled and power input, from 230–400-v 50-cps supply, is 30, 75, or 90 kva according to the equipment combinations in use.

621.396.61.029.56/.58 777

S.F.R. 2-kW and 20-kW Single-Sideband Transmitters—G. Pembose. (*Ann. Radioélec.*, vol. 4, pp. 358–371; October, 1949.) An illustrated description, with block and circuit diagrams. The advantages of single-sideband operation are outlined and the application of the normal suppression method to these transmitters is discussed. The use of quartz filters reduces the number of frequency conversions necessary to three, which are effected at 84 kc, at 2,520 kc and at a variable frequency. Each transmitter has a frequency range of 3.75–23 Mc and includes an automatic quick-action frequency-selection device. Cw and AM telegraphy, and telephony operation can also be arranged; in single sideband working a "pilot frequency" signal is transmitted for demodulation purposes at the receiver.

VACUUM TUBES AND THERMIONICS

621.383.4 778

A New Germanium Photo-Resistance Cell—J. N. Shive. (*Phys. Rev.*, vol. 76, p. 575; August 15, 1949.) A description of a device using a photoconductive property of germanium which combines high spatial resolving power with an over-all quantum efficiency greater than unity. The electrode geometry is similar to that of the double-surface transistor. The characteristics of the collector are modified by the photo-liberation of charge in the neighboring semiconductor. The responsive area on the germanium is confined to a small region on the illuminated side immediately opposite the collector contact. Specimen static characteristics are given showing load power responses

of the order of several tenths of 1 mw per millilumen. The cell response to different light modulation frequencies is flat up to the highest frequency studied, about 200 kc. The response rises slowly from the visible yellow to a peak at 1.5 μ and decreases rapidly beyond 1.6 μ.

621.385.032.213:537.581 **779**
Thermionic Electron Emission from Carbon—Ivey. (*See* 604.)

621.385.2 **780**
Cathode Field in Diodes under Partial Space-Charge Conditions—H. F. Ivey. (*Phys. Rev.*, vol. 76, pp. 554–558; August 15, 1949.) A method is given for calculating the electric field at the cathode of a plane or cylindrical diode as a function of diode current. The results are believed to be applicable to any electrode geometry and to the study of thermionic cathodes in the Schottky emission region. The effect of anode voltage on cathode field, and the potential distribution in a plane diode are also discussed.

621.385.2:537.525.92 **781**
Diode Space Charge for Any Initial Velocity and Current.—L. Page and N. I. Adams, Jr. (*Phys. Rev.*, vol. 76, pp. 381–388; August 1, 1949.) "The space charge equation is solved for any initial velocity which is the same for all electrons and for any realizable current, for (a) the plane diode, and (b) the cylindrical diode. For the plane diode it is shown that all cases can be obtained from a single pair of master curves. For the cylindrical diode a series valid for large distances from the axis is obtained first, the form of which shows that the complete group of solutions form a bounded set. Next three solutions valid for small distances from the axis are obtained by means of which the first set of solutions can be extended. In addition to master curves representing these solutions, curves are plotted for special values of the initial velocity and current."

621.385.2:[621.397.62:621.396.615.17 **782**
The Efficiency Diode in Television Line Time Bases—N. Coxall. (*Philips Tech. Commun.* (Australia), No. 4, pp. 3–8; 1949.) Description of the miniwatt diode Type EA40, with emphasis on the increase in line timebase efficiency and on the circuit simplification possible when this diode is used.

621.385.3 **783**
New Triodes for Metre and Decimetre Waves—L. Liot. (*Radio Franç.*, No. 11, pp. 3–6; November, 1949.) A description is given of the Type T3OH disk-seal triode constructed by the S.A.D.I.R. The electrodes are cylindrical and the tube is used in a vertical position. Maximum anode and grid voltages are 1,000 v and −200 v respectively. Maximum anode dissipation is 30 w and the upper frequency limit about 700 Mc. The construction details are given of a symmetrical twin-line oscillator using two such tubes. Circuit characteristics and operating conditions are given for four frequencies in the range 220–400 Mc.

621.385.38 **784**
Pulse-Controlled Thyratron—J. G. Skalnik. (*Electronics*, vol. 22, pp. 120, 168; December, 1949.) A short positive pulse of variable phase with respect to the 60-cps anode voltage of a positive-grid thyratron controls its conduction period.

621.385.83:538.691 **785**
Study of the Magnetic Focusing of Cylindrical Electron Beams—G. Convert. (*Ann. Radioélec.*, vol. 4, pp. 279–288; October, 1949.) See 485 of March.

621.385.83:621.396.615.142:538.691 **786**
Magnetic Focusing of a Cylindrical [electron] Beam with Density Modulation—R. Berterottière. (*Ann. Radioélec.*, vol. 4, pp. 289–294; October, 1949.) The transverse dispersive forces in an irregular electron beam are considered, and the behavior of such a beam in a compensating magnetic field is discussed. Space-charge effects lead to considerable values of the radial debunching force, so that a magnetic field variable along the beam according to a certain law is necessary. Oscillations of electrons situated between two packets are minimized by using a sufficiently strong field.

621.396.615.142.2 **787**
Beam-Loading Effects in Small Reflex Klystrons—W. W. Harman and J. H. Tillotson. (PROC. I.R.E., vol. 37, pp. 1419–1423; December, 1949). Beam-loading Q is determined from separate measurements of Q for tube and cavity (a) without and (b) with the accelerating voltage applied. Loading effects are much greater than predicted by published analyses; they vary approximately linearly with total oscillator load, a variation not previously noted. Analysis of loading effects produced by secondary electrons ejected into the intergrid space by the main electron stream shows the beam-loading to be large, with linear variation with load, and indicates the possibility of negative beam-loading.

621.396.622 **788**
Theoretical and Experimental Study of Detection by Silicon Crystals—P. Lapostolle. (*Onde Élec.*, vol. 29, pp. 429–448; December, 1949.) An account of research, extending over a period of two years, on a selection of detectors of British and German origin, together with full discussion of a theory based on the classical equivalent circuit. The method of showing the voltage/current characteristic on the screen of a cro is described and static characteristics for actual detectors are given. Methods of determining the impedance of detectors at low frequencies and at frequencies up to 10 Mc are described and rectification characteristics in the range 30–100 Mc and at 500 Mc are shown. Impedance and power measurements at decimeter wavelengths are considered in detail. Experimental results for powers above 10 mw are compared with values calculated from the theory given. Agreement is satisfactory and observed variations can be interpreted correctly by the theory, which indicates a slow decrease of detector sensitivity with increasing frequency and stresses the importance, even at vhf, of a very high backward resistance.

621.396.645:537.311.33:621.315.59 **789**
The Transistron Triode Type P.T.T. 601—R. Sueur. (*Onde Élec.*, vol. 29, pp. 389–397; November, 1949.) Discussion of the properties of Ge, the effects at the point of contact between a conductor and a semiconductor, and the mechanism, construction, and applications of the transistron. See also 2978 of 1949. (Aisberg).

621.396.645.029.4/.52:621.396.822 **790**
Selective Amplification at Low Frequencies—de Queiroz Orsini. (*See* 596.)

621.396.822 **791**
Spontaneous Flucuations in Double-Cathode Valves—K. S. Knol and G. Diemer. (*Wireless Eng.*, vol. 26, p. 345; October, 1949.) Measurements at 6 Mc on a tube with two indirectly heated plane cathodes 1 mm apart, and on a second tube with directly heated tungsten filaments of diameter 100 μ and 0.5 cm apart, do not support Fürth's theory (2418 and 2419 of 1948).

621.396.822 **792**
Note on Transit-Time Deterioration—A. van der Ziel. (PROC. I.R.E., vol. 37, p. 1447; December, 1949.) A simple derivation of some formulas recently published by MacDonald (2408 of 1949). See also 1890 of 1948 (Strutt and van der Ziel).

537.533 **793**
L'Émission Électronique [Book Review]—J. Bouchard. Publishers: Librairie de la Radio, 160 pp. (*Radio Tech. Dig.* (Franç), vol. 3, p. 379; December, 1949.) "A book which should interest radio technicians, particularly those concerned with the manufacture of transmitting and receiving tubes, as well as students and physicists."

MISCELLANEOUS

061.3:621.3 **794**
A.I.E.E. Fall General Meeting Conference Papers Digested—(*Elec. Eng.*, vol. 68, pp. 1091–1098; December, 1949.) Authors' summaries of 27 papers read at the meeting.

621.396 **795**
I.R.E. [Australia] Radio Engineering Convention (*Proc. I.R.E.* (Australia), vol. 9, pp. 21–27; October, 1948.) Summaries of the technical papers presented at the convention held in Sydney, November, 1948.